



50th
Anniversary

50 Years Ago

The Office Of Naval Research

Became the First Federal Agency to Sponsor Scientific Research



ONR started here at T-3, a wing of the Main Navy Building on Constitution Avenue, Washington, D.C., in 1946. The mission of the new agency was stated in Public Law 588, "to plan, foster, and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power and the preservation of national security".



Vice Admiral Harold Bowen, who was a formidable force in establishing ONR, became the first Chief of Naval Research. A *Time* magazine article in July 1945 stated, "The US Navy knows Admiral Bowen very well. Stocky and bald, the fiery Admiral possesses a quality much rarer than courage in battle: an absolute fearlessness of superior rank when one of his pet projects is involved. His scrappy perseverance is a departmental legend." He browbeat the Navy into adopting new high-pressure, high-temperature steam turbines, which proved invaluable for World War II's ships. He was also a persuasive force behind the Navy's development of radar.

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Table of Contents

2

The Beginning

The Navy Looks Forward with Research
(Speech by CAPT Robert Dexter Conrad)

4

A Decade of Science

Ten Years of Naval Research -- The Decennial of ONR
(Reprinted from *Naval Research Reviews*, August 1946)

Acceptance remarks of Dr. Alan Waterman for the CAPT Robert
Dexter Conrad Award.
(Presented for the first time at ONR's 10th Anniversary)

15

Twenty Years

ALVIN's World
(Reprint from *Naval Research Reviews*, August 1964)

20

Thirty Years

Science and the Military Mission
(Delivered by Edward Teller at ONR's 30th Anniversary)

24

Forty Years

Early Days of Quantum Electronics and the Office of Naval Research
(Delivered by Charles Townes at ONR's 40th Anniversary)

29

Fifty Years

The Navy After Next -- A Technology Vision of the Future

38

Chiefs of Naval Research

Chief Scientists and Technical Directors

(Photographs from 1946 to present)

THE BEGINNING

The period following birth must be regarded as the time when the nourishment given to a child has the greatest effect on the development of the body.

Aristotle, Politics, c. 345 BC



The staff of the Navy's Coordinator of Research and Development at the close of World War II. Included in the photograph are the "Bird Dogs" who were instrumental in establishing ONR in 1946. The names of the "Bird Dogs" appear in bold print. Standing left to right: LT A. C. Bode; LCDR N. S. Barlow; **LT James Wakefield**; ENS Betty Cowie; LT James Parker; **LT Bruce Old**; LCDR John Burwell. Seated: LCDR Ralph Krause; CAPT Lybrand Smith; RADM J. A. Furer; CAPT S. F. Smith; CDR R. D. Conrad; LCDR H. Gordon Duke.

The Navy Looks Forward With Research

Excerpts from the Navy Day address given by CAPT Robert Dexter Conrad, Director, Planning Division, Office of Naval Research, at the University of Illinois, Urbana, October 27, 1946. CAPT Conrad was a primary architect of the Office of Naval Research and established the contract research program with universities.

The Navy has embarked upon a venture which is not only new to the Navy, but new to the Government, and which is of deep significance to the national welfare as well as the national security. This venture is the active and comprehensive support of research.

We hear a great deal these days about research with such qualifying adjectives as "ba-

sic," "fundamental," and "applied." These words "science," "engineering," "technology," and "development" are also popular, with qualifying adjectives. These terms have such a variety of usage that an intelligent discussion is impossible unless we define them. I shall use only two with very simple definitions: research means the search for new knowledge of Nature; development means the application of knowledge.

The decisive step was taken in May 1945, three days after V-J Day. The Secretary of the Navy established a main office for research in the Navy Department. Fifteen months later, the Congress confirmed the wisdom of this move by legislation creating the Office of Naval Research, which was approved by the President August 1, 1946.

This office has brought active financial support and encouragement to scientific research workers in all fields of science — including medicine — in all parts of the country.

Some idea of the extent of this plan is revealed by the latest summary I received before coming here. We have about 200 research contracts covering over 400 projects, totalling about 22 million dollars. More than three-quarters of this volume is placed with universities and colleges. Considerably more than half these projects are under \$25,000 apiece.

Curiosity is inherent in the nature of man. Scientific research is one of the highest manifestations of intellectual curiosity. Through research, science merges with philosophy as one of the great works of the

human spirit. The urge to conduct research cannot be denied. All research is beneficial. No quest for truth can be otherwise. Its results may be put to use for good or evil, but to stifle research would be to stifle the main hope of humanity. Developments have created fresh problems of staggering proportions. Only new knowledge can solve them, and it would indeed be a counsel of despair to deny aid to research because we fear its consequences.

From what I have said, it should be clear that it is a contradiction to speak of directing and controlling research. An unexplored country cannot be mapped. It is proper and necessary to plan development work, but research must follow only its inner prompting. Direction by an external authority defeats its own object, for neither path nor the goal of research work can be foreseen.

Science now requires more research than private enterprise can support. Universities can no longer depend on the generous endowments of prewar days. Their staffs are inadequate. Industry is supporting more and more research, but industrial laboratories will always be more concerned with development (as I have defined it) because industry's primary job will always be to produce. The tools of research are becoming more expensive. The government must therefore lend public assistance if the national interest is to be served, but this assistance must not degenerate into domination.

It is in accordance with this philosophy that the activities of the Office of Naval Research are conducted. The responsibilities of the Navy for the national security justify the expenditure of naval funds for research, since otherwise new developments will wither on the vine.

The most striking frontier of research is, of course, in nuclear physics, for we may expect atomic power developments from it. An immediate object of the Navy is atomic energy for ship propulsion. The United States Navy, as any of you know, is the largest consumer of power in the world.

Another frontier of research lies in the study of materials near the absolute zero of temperature. The electrical resistance of some metals vanishes at this extreme cold, and electrical currents circulate indefinitely. This is called superconductivity.

A better knowledge of the upper air is needed before any further significant advances can be made in the propagation of radio waves. Perhaps the highways of swift aircraft lie far above present heights. Certainly rockets are the natural power plants at vast altitudes. And as we push forward from this frontier, the dream of interplanetary navigation comes within reach.

The sea is an endless research frontier, and one discovery in particular has excited a great deal of interest. A deep sound channel has been found, in which sound waves travel great distances without much loss in intensity. It is somewhat like a speaking tube in the ocean, and lies at various depths which depend mainly on the water temperatures—in some cases three or four thousand feet down, in others fairly near the surface.

The two new power plants for aircraft are the turbojet and the gas turbine, with rocket-type plants around some future corner. The turbojet, which powers the most advanced fighter aircraft of the Armed Services, is merely a combustion chamber into which air is crowded by a turbine driven compressor, and the hot gases, driven out behind as a jet, provides the thrust that drives the airplane forward. The striking feature is the absence of a propeller. The other power plant consists of a gas turbine driving propeller, in place of the usual reciprocating engine. Both types of power plants promise greatly increased power for planes, with bigger and faster planes in the offing.

The war brought great advances in the art of computation, and the future is now bright for the mathematicians and those who must use mathematics in their studies. A machine called the ENIAC, built at the University of Pennsylvania for the Army Ordnance Department, can compute the instantaneous position of a projectile and determine its point of fall in a shorter time than the projectile is actually in the air. This machine occupies a room 30 feet by 50 feet and weighs 30 tons. It can multiply two ten-digit numbers in 1/360th of a second. Both the Army and Navy are supporting the research and development of still faster and more flexible machines.

One big job for a computing machine is in weather forecasting. You all are familiar with the weather maps which form the ba-

sis for the daily forecasts. We know something of the mathematics of meteorology, but it takes six months to do a complete mathematical job of predicting tomorrow's weather from today's observations. A computing machine might do it in a few minutes. Whether the weatherman would be more reliable if he had such a machine is open to debate, but at least he could pass the buck to a machine whenever it rains on your picnics.

The old securities of space and time are vanishing. Our powers of self-destruction appear like a baited trap which mankind is powerless to evade. Where is the new hope? Where is the new security?

The answer is in knowledge. The renaissance of research, to which the Navy is proud to contribute, can create the new knowledge and stimulate the education which are the foundations of a better world. In a more limited sense, the study of our research results will reveal the evil possibilities against which we must guard ourselves, and this is a natural responsibility of the Navy. But in the broad sense, the common enemy of mankind is man's ignorance. We must bend all of our energies to learning more and more of ourselves and the world around us. Research to create knowledge, and education to spread it to all people, are the basic safeguards of civilization, and the only weapons which will succeed against ignorance, our ultimate enemy.

A DECADE OF SCIENCE

*The ten year old gives a fair indication
of the man or woman he or she is to be.*

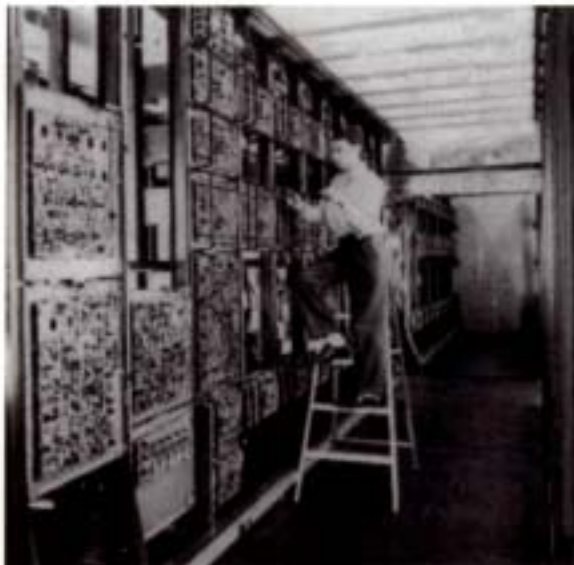
Arnold Gesell, *The Child from Five to Ten*, 1946



In the late 1940s, ONR sponsored "Skyhook," a project which carried scientific equipment by plastic balloons into the atmosphere to study cosmic rays.



ATLANTIS I was one of the first research vessels of the Woods Hole Oceanographic Institution and from her deck ONR funded some of its earliest oceanographic research.



ONR sponsored the development of the first full-scale digital computer to utilize magnetic core memory. The project known as "Whirlwind" began in 1946 resulted in a computer which remembered, acted upon, and delivered information at a rate of 20,000 times a second; a record achievement for the day. The "Whirlwind" computer filled a room when it was completed.



Professor Charles H. Townes is shown with the ammonia beam maser he developed in the early 1950's at Columbia University. This was the first molecular oscillator and amplifier and led to the development of the general field now called quantum electronics. This research was funded by ONR, the Army, and the Air Force.



Attendant in sterile plastic suit enters germ-free chamber where experimental animals used in dental research are kept at the Lobund Institute, Notre Dame. During the 1950s, "dental caries" or tooth decay was a major medical problem.



Arctic work station. Beginning in 1947, arrangements between ONR and the Arctic Institute of North America encouraged competent investigators to conduct field research in the Arctic.



This unique tilt-wing aircraft was built by Vertol Aircraft Corporation for the Army under the direction of ONR. This Vertical Take Off and Landing (VTOL) aircraft was designed to take off and land vertically, hover, and fly forward without any ground run. This aircraft is a research milestone in the development of the V-22 "Osprey" tilt-rotor plane of today.

The "Flyer Platform" built by Hillier Helicopters for ONR in 1955 levels off in free flight. It is the first aircraft using a ducted fan for lift and propulsion to attain free flight.



Biologist Carl Ekland pointing to penguins, Wildes Land, Antarctica, during operation DEEPFREEZE. This was an effort to delineate coastal features in little-known areas. The Navy needs to know about environmental conditions in all parts of the world to prepare for possible land, sea and air operations — the application of geography to military problems.



The Kellett KH-15, dubbed "Stable Mable," which was rocket-powered, flew in 1953. Stable Mable incorporated gyro-stabilizing controls designed to give helicopters greater stability in the air and cut vibration.

Hurricane photographic rocket on launcher at the National Advisory Committee for Aeronautics' Pilotless Aircraft Research Station, Wallops Island, Virginia, July 1956. One phase of the ONR program was to photograph from an altitude of 100 miles the entire hurricane cloud system.



Professor Norman F. Ramsey developed this first molecular beam apparatus at Harvard in 1950 with ONR support. This apparatus is the forerunner of new techniques being developed and used in high precision spectroscopy today. The separated oscillatory field techniques later used in cesium beam clocks were first developed for this apparatus. The on-going spectroscopy research of ONR is important to the Navy for increasing the accuracy of precision timing.



Ten Years of Naval Research — The Decennial of ONR

*Reprinted from
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August 1956*

On 1 August 1946, President Truman signed Public Law 588 which had been passed by the Seventy-ninth Congress. This law established the Office of Naval Research to plan, foster, and encourage scientific research in connection with its paramount importance as related to the maintenance of future naval power and the preservation of national security.

During the last decade ONR has been singularly successful in bringing together the scientific community of this country and our great Naval establishment. At the beginning of this period basic research and advanced study in most of the sciences were in need of encouragement and support. From the beginning ONR recognized that it could best solve its own problems and plan and organize its own program of research by helping to restore health and vitality to scientific research in the country as a whole. The problem of overcoming the scientist's distrust of any bureaucratic direction of research, especially by a government agency whose whole mode of operation depended upon authoritarian control, was very formidable.

ONR established workable policies that fully recognize and respect the scientist's need for independence and freedom. This resulted in part from a long tradition of Navy utilization of scientific knowledge. Solution of this problem provides the key to the achievement of the Office of Naval Research during its first ten years. Virtually all its other and more obvious achievements result from this one.

ONR is the Navy's representative in the world of science, and a spokesman for science in the councils of the Navy Department. Its mission is to make available whatever science has to offer which might result in modern weapons, devices, and techniques, so that now and in the foreseeable future the United States Navy will be superior to any in the world.

To do this ONR must know, on the one hand, the needs of the Fleet. What advances should we be making in submarines?

What kinds of new radar and sonar equipment do we need? What kind of aircraft should the Navy have?

On the other hand, ONR must know what is going on in science that will help to meet the needs of the Fleet. It must know the latest theories concerning the physical forces acting on a moving body underwater, such as a submarine; about cosmic ray activity and very high altitude weather conditions for high-speed, high altitude flight; the areas scientists are exploring in order to become aware of new findings that might hold some promise of use to the Navy.

ONR's program began with the activation of a series of basic research projects in the physical, biological and naval sciences. Then, as now, the staff evaluated the programs on the basis of the Navy's needs, scientific merit, and budget.

The year 1954 marked the beginning of an era of changes in the Navy's administrative setup for research and development. These changes are all in the direction of a more formal integration and coordination of research and development. ONR became the central point for coordinating the many development programs being carried on by the technical Bureaus. The Chief of Naval Research now combines the research and development budget requests of the Bureaus and the Marine Corps into a single appropriation.

The real heart of ONR's work is its contract research program. About four-fifths of its research is carried out through contracts with universities, with commercial and industrial laboratories, and with non-profit laboratories and institutions. Through its position in the scientific community, ONR has succeeded not only in keeping the Navy in the front ranks of science, but it has kept scientists interested in problems peculiar to the Navy and has maintained a nucleus of these specialized scientists working on current Navy projects.

For example, the Navy needs to know about environmental conditions in all parts

of the world to prepare for possible land, sea and air operations; it needs to apply geography to military problems. ONR's geographic research on little-known areas, particularly coastal areas, has been used by both the Navy and the Marine Corps. New information obtained through geographic research provides a source of reliable, basic knowledge, ready and available as the Navy's needs arise. Thus, Task Force 43 (Operation DEEP FREEZE) is using information from a project begun in 1952 to delineate the coastal features of Wilkes Island, Antarctica. As a result of ONR's ceaseless efforts, geographers are thinking increasingly in terms of research that will benefit the Navy and are prepared to apply their skills and knowledge to the solution of naval problems.

A great variety of hydromechanics research has been supported to solve many of the pressing problems that arise during the development of high performance weapons and vessels. Contractors seven years ago began to investigate the potentialities of hydrofoil boats for naval applications. The excellent speed and seaworthiness of hydrofoil craft have been demonstrated in all types of waves. Hydrofoil boats up to 50 tons can now be designed and sail boats equipped with hydrofoils have been successfully tested. A contract for a prototype hydrofoil landing craft has been awarded.

Scientific investigation is the root of continuous improvement of military equipment and of effective techniques for their use. Program analysis groups therefore continuously survey the scientific activity to insure there are no gaps in the research program. They try to channel ONR's research funds into those areas most likely to produce usable results. In view of the nature of basic research, such a plan is always difficult. Basic scientific research seeks to find the underlying principles that govern physical phenomena. These principles form the basis for subsequent development of better products for the Navy and the nation.

The first program of basic research sponsored by the Physics Branch in 1946 was the study of low temperature physics, or cryogenics. This program consisted of research in superconductivity, cryomagnetism, superfluidity, specific heats and calorimetry, thermodynamics, and thermometry. This program is considered by many outstanding physicists to have been the finest example of government-sponsored academic research to date. As a result of the cryogenics program, liquid helium became easily and cheaply available and techniques for its use lost their esoteric character. Subsequently, research in solid state physics was joined to cryogenics research. This union, with its almost revolutionary consequences, laid the foundation for much of the later work on the hydrogen bomb.

Just last year a series of electronics tasks supporting radio astrophysics and related research was initiated. This dramatic, relatively new science studies details of solar emission. Seemingly pure and far removed from practical applications, it is already making its contribution to navigation, communications and other areas of naval importance.

ONR's contractors frequently develop a new idea until the principle is either proved or disproved. Then the Bureaus take over and use the basic information for their particular requirements. For example, the Air Branch develops fundamentally new concepts in the field of aeronautics that are used later by the Bureau of Aeronautics. It supported early research on very light, one-man helicopters. The KH-15 was built with adjustable linkages that could be easily varied during flight. This helicopter demonstrated outstanding flying qualities in free flight after less than 10 minutes of ground tie-down testing. This is particularly noteworthy since very small helicopters are characterized by lack of stability, excessive control sensitivity or both.

Recent research efforts came to fruition this year in the actual flight testing on a high-performance military aircraft of boundary layer control systems. BLC involves taking power, in the form of compressed air, from the jet engines. Through a system of ducting, it energizes the "dead" air adjacent to the surfaces of the wings and increases

their lifting power. Reduction in take-off and landing speeds for high-performance aircraft has been demonstrated by flight tests with an F9F-4 aircraft for the Bureau of Aeronautics. Under ONR contract, six different circulation control systems have been successfully flight tested on light planes and are available with modifications for application to service type aircraft.

As a result of ONR's studies of noise reduction, the Bureau of Ships established seven groups in naval shipyards to work on ship and machinery noise reduction problems. Precise study of the effects of wave motion upon given hull shapes at varying speeds involves extremely complex mathematical operations. The mathematical research performed by ONR contractors has provided new knowledge of differential and integral equations of value in solving the ship designer's problems.

Research programs produce a wealth of information. To get this information to the proper place, ONR provides for individual contacts throughout the Navy. This continual working-level association is the heart of its technical information network.

One method of bringing people together to discuss their problems and learn of the latest developments in a specific field is by symposia. Since 1946 the seven symposia on undersea warfare have permitted the exchange of ideas between operating forces and civilian scientists and engineers. During one symposium strong recommendations were made for the initiation of the low frequency underwater detection research program.

These symposia promote the cross-fertilization of ideas that come from contact with many different scientific disciplines and engineering fields. In classified areas of research, such as underwater acoustics, these symposia serve as a substitute for professional society meetings.

Research results are also made available to the other services and frequently adopted by them for development. Fundamentally new concepts in aeronautics are constantly studied. One such concept, that of vertical take-off and landing (VTOL) is now being developed by the Department of the Army in cooperation with ONR. The first research work on convertiplanes in this country was sponsored by ONR in 1948.

The Air Force is developing an experimental aircraft, the XV-1, based on these VTOL investigations begun in 1949. Still undergoing flight tests, it has flown a speed range from 0 to 193 mph.

Theoretical research performed over a period of years in several countries coupled with existing knowledge led to development of a prototype of a simple, wingless aircraft, "The Flying Platform." The Army Transportation Corps is now adapting it to their specialized requirements.

Project SQUID, a program of research in basic science bearing on the problems of jet propulsion, began in 1946 as a cooperative venture on the part of the Bureau of Aeronautics and ONR. The other services have adopted ideas, results, designs, views and devices that originated or were nurtured in SQUID. A 12-volume set of books covering most of the present unclassified knowledge in jet propulsion and high speed aerodynamics, initiated under Project SQUID in 1949, is nearing completion. Work on the air-turbo-rocket has reached the development stage and the Air Force is pursuing application of this engine for its specific needs.

The history of the shock tube program is particularly significant, due to the fast growing popularity of the device, once called "the poor man's wind tunnel." Ten years after the original group was started at Princeton, ONR supports six shock tube tasks at universities and one at the Naval Ordnance laboratory. Results are used by the Air Force, NACA, and the aircraft industry.

ONR joins with the other services in co-sponsoring relatively large tasks. For example, it has co-sponsored with the Army and the Air Force electronics research at Massachusetts Institute of Technology, the Research Laboratory of Electronics, the Cruft Laboratory and others.

These three-Service tasks serve as efficient flow channels for interchange of information on specific research; establish unified service operations at working levels; and provide nucleus research centers to permit build-up of applied laboratories in case of a national emergency. The Lincoln Laboratory at MIT, originally a basic Air-Defense research group at MIT's Research Laboratory of Electronics, is well recognized as an important contribution of the three-

service, non-government, laboratory type of operation.

ONR's vigorous program of electronic digital computer development led to development of the Institute for Advanced Study's electronic computer — the ancestor of an extensive family of computers. The Whirlwind computer, developed at MIT, has made a major contribution to the development of the SAGE system of continental air defense. Whirlwind is still one of the fastest machines in operation. Its magnetic core memory is probably its most striking contribution to the art.

As the three services are only as effective as the personnel who man their equipment, research on human factors has comprised a large part of the ONR program. Papers presented at a conference at the University of Michigan in 1950 were published as a volume, "Groups, Leadership and Men." This book, summarizing the experimental methods and principles of social behavior, is widely used in the personnel operations of the Armed Services as well as in social science research and operations in general.

The psychophysical characteristics of the human operator in performing numerous complex military tasks have not been overlooked. The ONR-sponsored BENOX report was the first attempt to evaluate and anticipate the impact of high intensity jet noise upon personnel and operations. It led to the formation of the Armed Forces-National Research Committee on Hearing and Bio-Acoustics. Personnel training must be constantly changed and modified to keep pace with new weapons and techniques. ONR constantly strives to anticipate these trends in order to prepare for adequate personnel training.

By keeping in close contact with the scientific community, ONR is able to provide a base for rapid mobilization in times of emergency. During the Korean emergency, for example, Naval Research Reserve Unit One, a volunteer research reserve unit, was quickly mobilized for active duty. This group of biologists, working as a team, studied fatigue in combat.

Scientists who have worked on ONR-sponsored programs constitute a pool of skilled men who are available as the occa-

sion arises for special work for the three services. One such group has actually conducted field research in remote and foreign areas, often under rigorous climatic conditions, for the Geography Branch. For the most part, these trained observers have acquired broad first-hand and specialized knowledge of these areas; they have developed special ability to conduct research under difficult, strange or extreme conditions. Recently many of the more than 200 scientists experienced in Arctic projects have assisted the Navy in Operation DEEP-FREEZE, the Air Force in construction and supply of the DEW line, and the Army in its Greenland operations.

ONR also works with other government agencies. One of its most important programs in this respect was initiation of the application of electronic computation to dynamic meteorology. Since 1946, this project has grown into a complete operational program of numerical weather forecasting under joint sponsorship of the Navy, Air Force and Weather Bureau. Within a few years, meteorologists should be able to forecast weather with nearly 100 percent accuracy. ONR's contribution to this year's intensive study of hurricanes will include high altitude photography from balloons and rockets (*Research Review* June 1956). The National Bureau of Standards and ONR cooperate in an extensive basic instrumentation program to advance the state of the art.

Nuclear physics research, begun in 1946, prevented a time lag of two years in acquiring basic information and helped to restore a supply of essential scientific manpower. The program was so vast that the Atomic Energy Commission joined with ONR in 1947 to begin a continuing co-sponsorship of basic research that has become one of the major basic research programs of the country. A close, salutary working relationship exists between personnel of the two agencies. Development of a whole family of accelerators has resulted from the program. Cosmic rays have been studied at many latitudes from the equator to the Geomagnetic North Pole on both land and sea.

Certain early tasks in aeromechanics research matured rapidly in response to the

advancing needs of actual aircraft; their growth demanded more financial support than ONR could give. This led to joint support of many tasks with NACA and the Air Force, and eventually to sole support by these agencies. Many of the original ONR contractors are now working very productively in NACA and Air Force programs.

Many results of ONR research are classified, designed to answer specific military problems. Many benefits, however, occur from this research that are beneficial to the nation at large. New basic scientific information eventually benefits all society. Scientists working under the contract-research program publish their findings in professional journals when they are not essentially military. These findings then funnel down to the public through better production techniques, better materials, and better products. ONR also turns over much of its information to industry to encourage more efficient production at rates that will benefit the government.

ONR foresaw the demands that a successful computer development program would make on mathematics and mathematicians. From the beginning it embarked on an ambitious program in numerical analysis; it trained programmers and coders. ONR constantly advocated more research and training in what was then considered a most unattractive field by the mathematical community. The Institute for Numerical Analysis at University of California, Los Angeles doing contract research, attracted some outstanding mathematicians. It is interesting to note that as computer centers spring up all over the country the numerical analysts who are the mainstay of the ONR program are repeatedly approached to take over their directorships.

Publication of the *Digital Computer Newsletter* gives industrial and academic people involved in computer research and development up-to-date information on the state of the automatic digital computer art in this country and to some extent abroad. Its published reports have been particularly valuable as a reference. This information has helped to develop computers designed for its specialized requirements and to use numerical analysis to solve its complex problems.

Research in the biological and psychological sciences produces innumerable benefits for the civilian economy. In these areas the benefits are often immediately apparent whereas in other research the carry-over comes later.

A revised concept of the nature of burn shock brought about a new treatment. As all functions of the human body are regulated and coordinated in some way by the nervous system, a broad program in neurophysiology was initiated in 1946. Data obtained have made possible the development of new agents and procedures for relief of fatigue and pain, for the promotion of alertness and rejuvenescence, for the control of autonomic imbalance, for the treatment of tension and anxiety, and for surgical repair and rehabilitation.

Special studies in the field of flying safety, undertaken to improve military aviation, led to design principles and concepts that have been adopted by all experts in flying safety. The program has had a profound impact on the aviation industry throughout the world. Travelers in many modern transport airplanes enjoy safety measures developed under this program. Manufacturers of new type aircraft now on the drawing boards are taking advantage of advice and recommendations provided by these crash analysis experts.

Medical advances include development of blood plasma expanders, new techniques for tissue preservation and transplantation, new antibiotics, plastic "artificial corneas" to replace damaged corneas have been successfully tested in animals.

Growth of the Laboratories of Bacteriology, University of Notre Dame (LOBUND) is due in large measure to ONR's support. Here animals are raised in a completely germ-free environment. Thus it has been possible to prove a long-held hypothesis that bacteria cause tooth decay. Germ-free animals fed a sterilized cariogenic diet have no caries. Control animals raised in a normal environment and eating a regular diet have caries.

Studies of marine organisms, a part of the hydrobiology program, is directed in part toward preventing damage to wooden port structures, to metallic substances subject to

corrosion, and to ship hulls. Marine borer attacks cause annual damage of \$850,000 to wooden structures in waters surrounding the United States. Scientists are busily searching for a method to prevent such attacks. Survivors forced down at sea need to know what marine life to avoid and what can be utilized—particularly for food. Hydrobiological research helps to provide this all-important information.

Many developments in commercial aviation stem directly from the work done by ONR's contractors. Presently, in cooperation with the Bureau of Aeronautics, ONR is supporting research on development of aircraft instrumentation that will permit aircraft to operate in all kinds of weather with a minimum of cost in equipment weight and pilot training and a maximum gain in reliability and efficiency. A transparent, flat-plate television tube will replace many instruments in today's cockpit and permit safer flight.

The core of any nation's scientific resources has always been in its centers of learning, the colleges and universities. There most of the real pioneering work in science is still carried on. There men and women search for new knowledge about the universe, often with no thought of practical application, but simply because they are driven by an urge to know more about the world. Their discoveries lie at the basis of all the development and engineering work that leads to new products and new processes.

This program has been mutually beneficial to the scientific community and ONR. For example, research in the mathematical sciences has provided statistical contributions to the solution of current, concrete military problems. Indirectly, it has aided the military in the development of a quickly-mobilizable reserve of professional statisticians familiar with the use of statistics in military applications. The program has provided intellectual stimulation to scientists for it has opened up new problem areas that require basic theoretical work in statistics and probability.

Many ONR investigators have received outstanding awards including the Nobel prize. Most recent recipient of this award was Dr. Linus Pauling for his work in deter-

mining the structure of a limited number of proteins by x-ray diffraction methods. Many play important roles in scientific organizations. Three past presidents of the American Psychological Association, for example, have been principal investigators on ONR contracts. The American Mathematical Society's Bacher prize, awarded every five years, has gone to ONR contractors twice.

The contract research program with universities also affords an opportunity for students to do research leading to advanced degrees. At war's end, less than 30 Ph.D. degrees were granted in physics. Today, due in a large measure to ONR's sponsorship of basic research in physics, approximately 115 Ph.D. degrees in physics are given annually. Tomorrow's scientists and engineers can only be trained through basic science carried on in the universities.

ONR's impact on the scientific community includes:

1. Release of immediate financial pressure on creative scientists—more money for supplies, equipment and assistance,
2. Support for post-doctorate personnel,
3. Support for retired, but still productive scientists,
4. Development of a pattern for administration of government support to basic research. Red tape held to an absolute minimum,
5. Training of administrators, (Two program directors of the National Science Foundation were first administrators of ONR contracts)
6. Stimulation of scientific communication by support of conferences, symposia, foreign and domestic travel,
7. Freedom to pursue his study with a minimum of interference.

Cordial relations have been maintained with the scientific community abroad. A branch office in London provides constant liaison and keeps ONR scientists informed of the latest foreign scientific developments and trends. The Acoustics Branch early recognized that opportunity to make a major contribution to underwater sound, (see article in *Research Reviews* for August 1956,

"How Fast does Sound Travel in Sea Water?"), could best be obtained through a co-operative effort with British research and development in this field. Opportunities were provided for personal contact of technical people at the working level with a most salubrious effect.

ONR's work is increasingly recognized abroad as evidenced by awards presented to its contractors. A Yale scientist, working on a long-range program in radio astronomy has received the gold medal of the British Royal Society for his work on this program.

ONR is assisting foreign scientists with their research projects. Nuclear emulsion packages were flown for a group of European scientists during SKYHOOK launchings in Texas in 1955. Eleven scientists, members of CERN, the European Organization for Nuclear Research, wrote the Chief of Naval Research:

"The undersigned, on behalf of eleven European laboratories engaged in research on cosmic rays, wish to express their gratitude to the Office of Naval Research for its valuable help in arranging for the exposure of stacks of photographic emulsions at high altitude.

"In thus making it possible for us to take advantage of high altitude balloon flights, ONR has made a significant contribution to scientific cooperation at the international level. We feel sure that important results will flow from this type of collaboration."

ONR will conduct many experiments during the International Geophysical Year—particularly in the upper atmosphere. This area of research has been actively studied by ONR ever since its organization. Its earliest upper atmosphere research project, HELIOS, started in 1946, envisioned a manned flight to the stratosphere. A cluster of 100 balloons would carry the manned gondola to the stratosphere as one step in a series of upper air research and exploration programs using manned and unmanned craft. The state of the art of balloons, however, had not advanced sufficiently to make this manned flight possible.

To learn more about cosmic rays, temperature and density of the atmosphere and other related data, scientists needed an instrumented laboratory that would remain aloft longer than the rockets then used to

obtain essential data. Research produced the plastic SKYHOOK balloon since used extensively to probe the upper atmosphere. The data brought back has helped scientists piece together a better description of conditions to be encountered beyond the earth's atmosphere. This information has already made it possible for man to fly to heights undreamed of a few short years ago.

In pursuit of basic knowledge of the upper atmosphere, ONR has utilized new tools and techniques. Because of its vast experience in this phase of research, that began with Project HELIOS, the Chief of Naval Research was designated to produce and launch a small, unmanned scientific satellite as a part of the U.S. contribution to the International Geophysical Year.

Thus, ONR, since its inception, has represented the Navy in science, coordinated naval scientific research, maintained liaison with the scientific community both in this country and abroad, and cooperated with other government agencies in furthering basic research. It has supported scientific research in nearly every major scientific field, and its research results have made possible a new Navy, second to none. Countless significant benefits have also accrued to the civilian economy.

ONR will continue to be deeply involved in science in order to keep abreast of scientific progress and ahead of its competitors. A hundred years ago, when science was a casual, slow-moving effort, the Navy could afford to wait to adopt a new piece of machinery until an inventor had worked it out. Today, however, scientific research is a broad, organized, expensive, fast-moving effort. No longer can the Navy afford to be a mere spectator, standing by to purchase the results if they appear useful. It must actually be in science. It must conduct its own research and support the work of others. Thus, the Office of Naval Research will continue its support of basic research to meet future emergencies that will require the nation to be self sufficient in all fields of science.

The period from 1 August 1956 through 31 July 1957 was designated as the Decennial Year of the Office of Naval Research. This period provided a fitting occasion for the Office of Naval Research to evaluate

its past contributions to our national defense and to make definitive plans for the coming years. The various intra- and inter-Navy symposia, conferences, publications, etc., that are traditionally sponsored by the Office of Naval Research will, during this Year, be of pointed significance to the Navy's interests in research and development.

Acceptance of Captain Robert Dexter Conrad Award

by

ALAN T. WATERMAN

Director, National Science Foundation

Presented at ONR's 10th Anniversary Symposium

Mr. Secretary, Admiral Bennett, Dr. Astin, Ladies and Gentlemen:

It is a deep personal pleasure that I should be the first person to receive an award that honors a fine and courageous gentleman, Captain Robert Dexter Conrad. I am proud that he was my friend and my colleague during the exciting days that marked the beginnings of the Office of Naval Research. A man of vision and imagination, he did not hesitate to chart what in those days was a novel course for a Federal agency, and especially a military one — the general support and encouragement of pure research.

My entire experience with the Navy, first with the Office of Research and Inventions and then with the Office of Naval Research, I regard as one of the most rewarding of my life. The challenge of the opportunity presented by the Navy in the wisdom and forethought of its planning for the Office of Naval Research was very great. Such a challenge, together with the competence and enthusiasm of the members of the Office, both civilian and military, and the warm friendships among the Navy that grew during this association have been to me ample reward in themselves.

In my present capacity, I should like to add the compliments and respects of the National Science Foundation. The Foundation, established at about mid-point in the last decade, owes much to the pioneering efforts of the ONR. The wise and liberal policies of ONR in the administration of its research contracts have helped to set a pattern for new agencies as they have entered the field of research and development. The Foundation takes great pleasure in its continued close association with ONR.

At this point I should normally expect to stop. However, your program has me down for a formal "response," and I find myself in a dilemma. Every impulse leads

me to speak in the most glowing terms of the growth and the work of ONR, but the award which you have just given me inhibits my following that theme as eagerly as I should wish. I am sure, however, that all of us who have been associated with ONR would agree that if a single individual deserves recognition for the conception of the Office and the course of its future development in support of specialized and imaginative research, that individual is, without question, Bob Conrad himself.

During those beginning years in which we were feeling our way with new and experimental methods, Captain Conrad, as Head of the Planning Division of ONR, was an inspiring and stimulating leader. He proved that there is no barrier, real or imaginary, between scientists and the military, and that they are able to work fruitfully together. I had the fun of directing the scientific program, but upon his shoulders fell many of the administrative burdens of fitting the new Office and the new program into the long-established pattern of the Navy. The fact that we are, this week, observing the decennial anniversary of the ONR is ample proof that he did his work well. Today the Office of Naval Research is a familiar and respected name throughout the Government and in the academic and scientific communities as well.

It is a remarkable example of teamwork, with coordination and dedication of a high order shared by many from the Secretary of the Navy throughout the ranks of the Office itself. I interpret the award as a symbol of the Navy's feeling with respect to the role of the ONR in Naval affairs, and on behalf of those who were associated with the Office in its early days, I wish to express our deep thanks to the Navy.

I refuse, however, to let any sense of modesty stand in the way of expressing my high regard for the standard of performance of the

work of the Office in its recent years, and in this I echo the sentiments of the country, as you well know. A significant step in the growth of the ONR occurred when the Chief of Naval Research was instructed to take the lead in scientific research and development programs of the Navy. This was a logical move, because the Office of Naval Research occupied a central position in research and development and, at the same time, had broad and varied experience in the scientific and technical aspects of Navy programs. The present plan should prove an undoubted asset to the Navy in providing a suitable degree of centralized supervision while permitting the degree of autonomy that the Navy has traditionally associated with its bureaus. It also affords excellent opportunity for close cooperation with the Chief of Naval Operations on Naval requirements as they relate to research and engineering developments.

In these days of rapidly expanding budgets in our growing technology, we must face up to the problem of determining our ability to pay the costs in dollars, manpower, and organized effort for those areas of development that are necessary to our economic and defensive strength. There has been an uneasy feeling on the part of many that the problem of rising costs should be met in part by curtailing scientific research, which is the source of the ideas and data required for future developments. This would be a serious mistake. It is like saying that an industry should take prudent care of its future interests by failing to replenish its stockpile and sources of manpower and curtailing its libraries and reference facilities. We must have the scientific data, we must have the ideas. Where we need to exercise most careful discrimination is in the selection of the development work that can be undertaken most fruitfully. Such selec-

tion is itself a matter of research and can be powerfully assisted by research techniques such as operations research and high-speed computations. It is in this transition phase, as engineers often call it, that the Office of Naval Research, in its new role and in cooperation with CNO and the Bureaus, can make a great contribution to the Navy and to the country. The ONR is now competent and experienced in the appraisal and performance of research, and through the close association between scientists and engineers and Naval personnel it can bring the weight of its experience to bear on this, one of the most troublesome problems of today. In so saying, however, I do not wish to imply any decrease in ONR interest in

basic research; this provides the fundamental strength for its entire program.

But I do not intend to get started on a speech at this point. An old geologist friend of mine used to remark in after-dinner speeches:

*There is a thorn on every rose,
There's fuzz on all the peaches;
There never was a dinner yet
That didn't have its speeches.*

And there is more than the usual amount of fuzz when an old-timer gets started.

In expressing my deepest thanks to the Committee, to Secretary Norton, and to Admiral Bennett and to you, the Office of

Naval Research, my only regret is that Robert Conrad did not live to share this moment with us. He was, as you know, the victim of a malady whose mysteries will some day be solved by research. Although he was well aware of his own condition, he never lost his courage or his scientific objectivity, and he gave hope and encouragement to others. In accepting the award which bears his name, I do so in full recognition that it symbolizes not so much the achievements of one person as the teamwork which has grown up between science and the Navy in their common dedication to strengthening the United States and advancing the progress and welfare of mankind. Long life to ONR.



*CAPT Robert Dexter Conrad
architect of the
Office of Naval Research*



Conrad Award



*Dr. Alan Waterman
First Chief Scientist of ONR
and later Director of National Science Foundation*

TWENTY YEARS

*Live as long as you may, the first twenty years
are the longest half of your life.*

Robert Southy, The Doctor, 1834



Dedication of DNR's Tandem Accelerator at the California Institute of Technology (CIT) on December 1, 1960. President Lee A. DuBridge of CIT points out the high voltage terminal of the helium injector to visitors: Rear Admiral Rawson Bennett, USN, Chief of Naval Research, James R. Kilian of the Massachusetts Institute of Technology and Alfred P. Solan, Jr. The Tandem Accelerator is housed in the Alfred P. Solan Laboratory of Mathematics and Physics at CIT. The Tandem Accelerator was the largest of many accelerators built by DNR for experimental and theoretical investigations of light nuclei. One of DNR's first contracts in 1946 was awarded to Professor Charles C. Lauritsen of CIT for light nuclei research. DNR's continued support of this research for 25 years led to a better understanding of the processes which occur in solar energy producing nuclear reactions and nucleosynthesis.

The undersea habitat SEALAB-II is being prepared for christening at the San Francisco Bay Naval Shipyard on July 23, 1965. SEALAB-II was the second phase of the Navy's Man-in-the-Sea-Program, which was organized and carried out by DNR. The project involved three ten-man teams living and working a total of 45 days, at a depth of 205 feet, one mile off the coast of La Jolla, California. During the summer of 1964, there was the SEALAB-I Project, which was much less ambitious in scope. From its early days and continuing through the present, DNR has supported research on the physiological and psychological effects of living and working in confined and unnatural conditions. Such research enhances the productivity of personnel as they go about such tasks as deep sea salvage projects, studying marine life in its natural environment, and collecting geological and oceanographic data.



First Team Leader CDR M. Scott Carpenter checks out the life support system used by the aquanauts in the SEALAB II habitat.



The first of the "monster buoys" which was designed by a committee of scientists from ONR and fabricated at the Convair Division of General Dynamics, San Diego, in 1960. This buoy was successfully tested in 1965 in the Gulf Stream and withstood the fury of Hurricane Betsy. Gathering synoptic data over broad geographical areas for long periods of time was the fundamental mission of the buoy, which has proven an invaluable aid for oceanography and weather prediction. Measuring 40 feet in diameter and weighing 100 tons, such ocean stations were capable of operating unattended for more than a year.

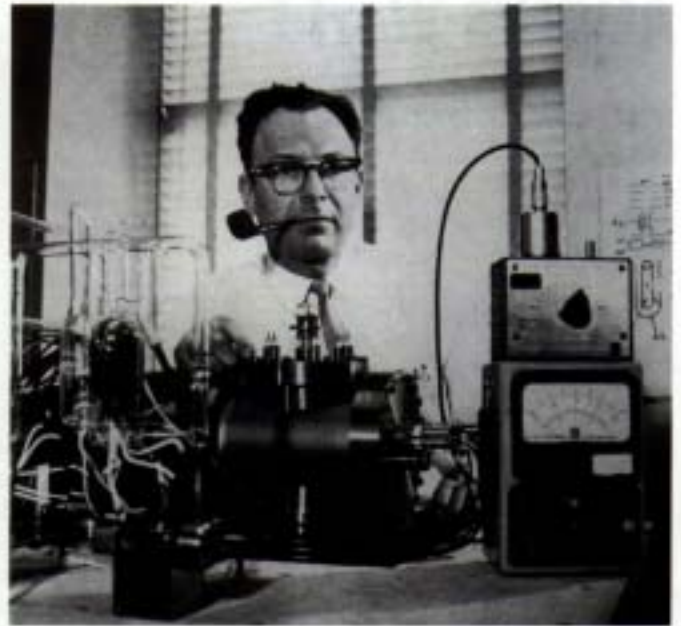


The Stratoscope II telescope, which was funded by ONR, is shown in launch position in 1963 during inflation of its carrier balloon. The launch balloon is filled with 350,000 cubic feet of helium. The telescope, lofted to an altitude of 80,000 feet, operated above 98 percent of the air and water "blanket" that surrounds the earth, and data was obtained free of the absorptive effects of the atmosphere. The balloon-borne telescope collected new and vital data on Jupiter and the giant, red stars.



Giant twin radio telescope, located in the Owens Valley, 260 miles from Los Angeles, was built in 1959 by the California Institute of Technology with funds from ONR. The telescope located and identified nine new radio sources outside our galaxy in the first two months of operation. During the formative years of radio astronomy, ONR was the major sponsor in the United States. The Owens Valley telescope was one of several built and operated with ONR funds during the 1950's and the 1960's

Professor George J. Schulz in his laboratory at Yale in 1965; the year he won the first Davilsson-Germer prize for his outstanding work in atomic physics. He was the first to observe helium resonance in the elastic scattering cross section of electrons from helium atoms. This new discovery opened the whole field of resonant electron scattering from atoms and molecules which has had tremendous impact on the understanding of e-atom, e-molecule interactions and subsequently helped in the development of gaseous lasers.



ONR developed the unusual vessel FLIP at Scripps Institution of Oceanography in 1962. This 355 foot floating instrument platform can be towed behind a ship in a horizontal position to its destination. Then, its ballast tanks are flooded, it tilts to an upright position, and all but 55 of its 355 foot length disappears below water, providing an extremely stable platform. It is used for research into such areas as wave attenuation; sound propagation, scattering, and reverberation; seismic wave recording; and measurement of internal waves.



TRIESTE (DSV-1) being loaded aboard the USS POINT DEFIANCE (LSD-31) by a crane in San Diego on April 15, 1963, for transport to Boston via the Panama Canal. The TRIESTE was transferred to the East Coast to investigate the sinking of the USS THRESHER (SSN 593), which she located on the second attempt. When the Chief of Naval Research, RADM Rawson Bennett, purchased the TRIESTE from France, he paved the way for the beginning of U.S. involvement in deep submergence research. On January 23, 1960, after a complete overhaul, the TRIESTE dove to a depth of 35,600 feet, a world's record. As her title (DSV-1) indicates, TRIESTE is the ancestor of hundreds of manned submersibles and remotely operated vehicles currently exploring the oceans. In the last four decades, the U.S. has become a leader in the designing, building and using of deep submergence systems.

ALVIN'S World

HON. JAMES H. WAKELIN, JR.

One of the "Bird Dogs" and
First Assistant Secretary of the Navy
Research and Development

Reprinted from Naval Research Review
August 1964

Over these past years, I have witnessed tremendous progress and accomplishment in the scientific endeavors made in support of the National Oceanographic Program. Of special interest has been the increased emphasis on the exploration of the deep ocean — the last true frontier on this planet.

Shortly after I took office, the bathyscaph TRIESTE made its historic 35,800 foot dive to the bottom of the Marianas Trench off Guam. Although this was a record dive and a notable "first," we of the Navy recognized that the event, in itself, made only minor contributions to science; it was important, rather, as one in a series of controlled tests designed to prove TRIESTE's capabilities for deep-ocean research. I think this point was lost to many people at that time. Coming as it did on the eve of manned exploration of space, the feat itself attracted more interest than its true meaning in terms of the future scientific investigation of the sea.

I emphasize this past history because I think too often we tend to stress the spectacular — the record altitudes and speeds, the machine rather than the intended purpose of the machine. This inclination is not unique to deep submersibles. All of us have witnessed the spectacular growth of aeronautics from the propeller driven aircraft of World War II to the manned space flights of today. Like millions of Americans, we have followed eagerly the achievements of a rapidly accelerating technology — a technology that hopefully will put our astronauts on the moon within the next decade. But our attention tends to be focused on the hardware, on the pilot, and on the "firsts." All too often the intended purpose of the mission is forgotten.

I for one, do not subscribe to the apparently sacrosanct belief that the mountain should be climbed because it is there, that a certain altitude or depth should be achieved because no man has previously flown or plunged so far. I believe that tools are de-

veloped to achieve a purpose. In a day when the development of tools demands such tremendous national resources, this purpose must be responsive to the interests of the Nation and its people.

ALVIN is one such tool. Although its designed depth of 6,000 feet is considerably less than that of TRIESTE, the speed, endurance, maneuverability, and range of ALVIN, plus its self-contained ballast system, permit us to call it a submarine. It will be the first deep-diving submarine to go into operation anywhere.

The men who are privileged to dive in ALVIN will see things that will undoubtedly make news for many years to come. But those of us in the Navy, industry, and at Woods Hole who helped conceive and bring her into being will be more concerned, I hope, over its impact on scientific research, particularly basic research important to the national interests. Our purpose is to advance man's knowledge of the sea; ALVIN is but one means to this end.

We have other objectives in the oceans besides research that demand tools for use in the deep-sea environment. Deep-diving military submarines are expanding the potential arena of naval warfare. We must understand this new and demanding environment. We must also be able to live and work in it.

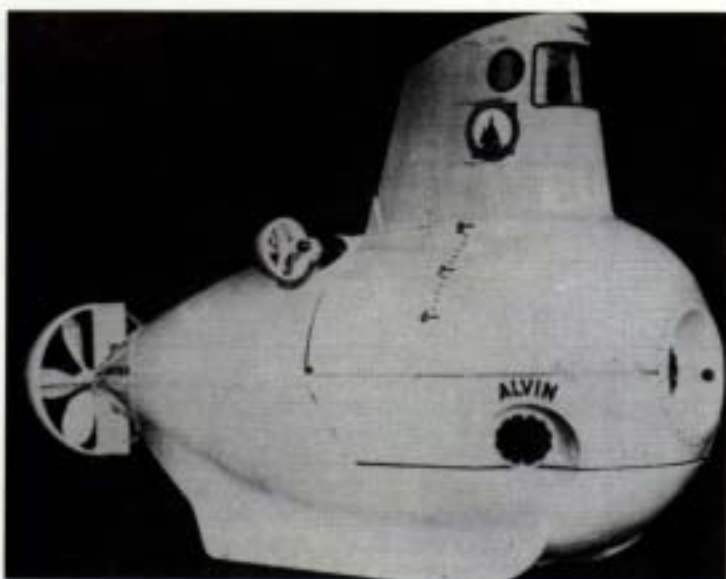
The tragic loss of the submarine THRESHER emphasized the pitiful inadequacy of our present technology to plumb the ocean's depth and perform useful work on the ocean's floor. Ship-lowered cameras, precision depth recorders, and other advanced oceanographic instrumentation were mobilized behind the search. But, in effect, we were groping blind from the surface. I know I speak for many of the men

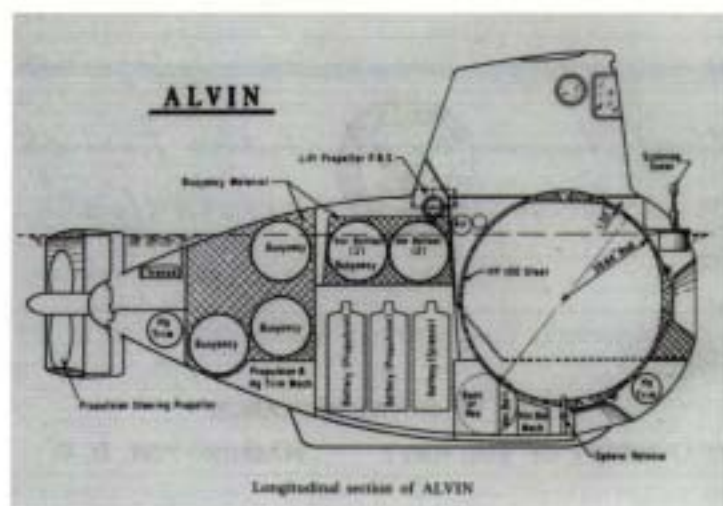
who joined the search for the THRESHER when I say that we were especially frustrated at our inability to employ the best sensor of all — the mind and eyes of man.

Eventually we were able to bring TRIESTE into the search. Her dives demonstrated clearly the advantage of selective, personal observation. Observers were able to confirm and photograph the location of structural parts of THRESHER on the ocean floor. In one of its dives, the bathyscaph used its mechanical arm to retrieve a length of copper pipe bearing markings which definitely established that it came from THRESHER.

But TRIESTE was not designed for search and recovery. It is in reality a slow, awkward, deep-sea elevator having little horizontal mobility, which greatly limits its area of coverage. Clearly, a new generation deep diving submersible must be perfected for this specialized work.

In April of last year, the Secretary of the Navy convened a group of prominent submarine officers, marine engineers, and oceanographers to prepare recommendations on what capabilities the Navy would require to locate, identify, rescue, and salvage objects of all sizes at any depth on the ocean's floor. In late May, the Secretary approved the recommendations of this group. Soon to be launched will be a program to advance our technology sufficiently to perform a variety of military missions in the deep ocean. The Special Projects Office will spearhead this effort; its past accomplishments on the POLARIS project argues well for the Navy's new deep-submergence program.





I would like to emphasize here that the vehicles and techniques presently under consideration by this group will not be developed primarily for oceanographic research. Certainly, the program will be of tremendous interest to the scientific community; in fact, we are depending in large measure on its support. But here again we are speaking of tools and purpose. Our main purpose in this respect is submarine rescue and salvage, and I think it would be unfortunate to confuse this purpose with oceanographic research.

On the other hand, I am confident that the technology resulting from the Navy's deep-submergence program will profoundly affect the development of structures, materials, and techniques needed to build the many tools of oceanographic research and ultimately those tools and engines needed for exploitation of the ocean's abundant living and mineral resources. I have in mind deep-diving submersibles to perform geological and geophysical exploration, to drill oil wells, and to mine minerals over the 71 percent of the earth's surface covered by ocean; tools to build underwater structures, such as tunnels, cables, and perhaps eventually villages beneath the sea; and deep diving submarines for tracking and observing commercially valuable fish, for fishing and aquaculture, and even for expanding our already flourishing sea-borne commerce.

Such predictions, no matter how fanciful they may seem today, will require expanded knowledge of the sea. This knowledge can be developed only through scientific research. The job is so big that vehicles needed for research must be designed and built for this specific purpose and no other.

The first such vehicle is ALVIN. With ALVIN we can greatly accelerate the exploration of the vast ocean depths. Nearly one half of the water volume of the ocean and neighboring seas will be accessible to the scientists who will

use her. This area includes most of the life of the sea. ALVIN will be capable of exploring one-sixth of the ocean's bottom, an area almost equal to the surface of the moon.

ALVIN will help solve many of the practical problems long tolerated but never really accepted by the sea going scientist. Understand there is a saying among biologists that towing a sampling net through the ocean is like running madly through an open field blindfolded holding a butterfly net above one's head. ALVIN will put the biologist where he belongs—in the center of the marine environment with his net and eyes open. Here he will be able to observe directly the concentrations and behavior of marine populations. The interaction of animal life and the environment can be studied throughout the water column.

Ideally, the marine geologist would like to do on the sea floor what he does on land — walk or fly over areas of interest, collect specimens, and study and map significant features and phenomena. ALVIN is the first step toward eliminating present blind, hit-or-miss methods of bottom sampling. The geologist, instead of groping awkwardly from a rolling platform thousands of feet above his rock dredge or poking random holes in the ocean floor, will finally be able to make discriminating, personal observations. Samples can be collected with ALVIN's mechanical arm, and photographs can be taken with its cameras.

The vessel also promises to be of great value in physical oceanography. The speed and direction of undersea currents can be measured more accurately. As ALVIN drifts slowly downward through the water column or uses its propellers for vertical movement, scientists can obtain continuous profiles of temperature,

salinity, and other water characteristics. Other potential uses of ALVIN, some of which cannot now be anticipated, will be made as this research tool extends the eyes and ears of oceanographers to the unexplored regions of the ocean's deep frontier.

ALVIN and the deep-diving research vehicles that will undoubtedly follow her promise sufficiently exciting dividends that I have requested the Interagency Committee on Oceanography, of which I have been privileged to be chairman for the past five years, to prepare a plan that will allow our member agencies to apply this unique tool to problems important to national security and welfare. I believe our optimism is well founded. Future development and wider use of the deep-diving research vehicle will depend in large measure on operational experience and research results. ALVIN, as a new research tool, is expected to play a major role in providing this essential experience while advancing the science of the sea.

As we inaugurate this great new adventure into the realm of the unknown beneath the sea, we should recognize especially the imaginative planning and determined efforts of the several organizations that have turned ALVIN from a concept into a reality.

THIRTY YEARS

Strength of body, and that character which the French term a physionomie, women do not acquire before thirty, any more than men.

Mary Wollstonecraft, *Vindication of Rights of Woman*, 1792



"Shakey" a mobile robot ancestor with TV eyes, tactile sensors, an optical range finder and an elementary navigation system connected to a large computer, performed autonomously in 1969. The Stanford Research Institute created Shakey with ONR funding. Shakey could plan and execute simple tasks such as finding objects and manipulating them in the laboratory while avoiding obstacles. The field of robotics or artificial intelligence has the goal of endowing machines with those characteristics that are called "intelligence" when exhibited by people. Many of the early concepts which ONR pioneered have become standard techniques such as: time sharing, systolic computing, neural networks, machine learning, and connectionist computing.



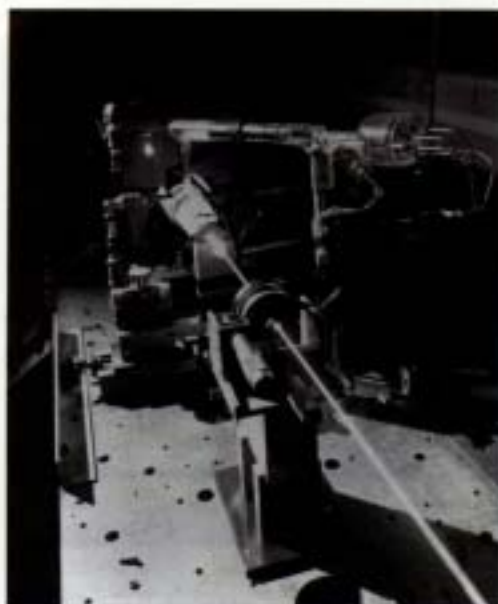
A magnetic sensor called a "SQUID" (Superconducting Quantum Interference Device) is housed in a liquid helium dewar held near the subject's chest. This device, which was developed by Dr. James Zimmerman of the National Bureau of Standards Research Laboratory at Boulder, Colorado, with ONR funding, made the first measurements of the magnetic field of the heart using a superconducting magnetic sensor in 1969.



Shown in this 1970 photograph is a General Electric Company engineer demonstrating Hardiman's left arm and hand assembly. During a test, the single arm easily lifted its design load of 750 pounds. The arm of the prototype Hardiman was the first completed and successfully tested part of a man-machine system worn by its operator like an outside skeleton. G. E. built Hardiman (the name is taken from Human Augmentation Research and Development Investigation) under contract to ONR. The prototype's two arms and two legs were planned in the design stage to mimic the movements of its operator and permit him to lift and operate loads of up to 1500 pounds.



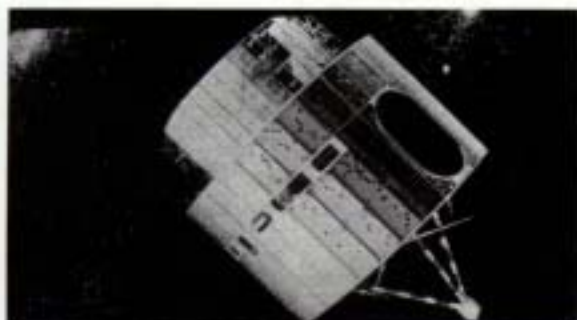
Diver (background) performing measurements in 1973 of flow resistance helium in the lung at 1600 foot depth while diver (foreground) is engaged in mental, visual and auditory measurements. This was part of a long-term program at the Institute of Environmental Medicine, University of Pennsylvania, supported by ONR. Research in the life sciences during this period provided fundamental knowledge concerning factors affecting man's ability to perform useful work in the underwater environment. Such work supported major elements of the Navy's Man-in-the-Sea Program.



One of the first argon ion lasers, which was built by the Gordon McKay Laboratory for ONR and was operational in 1967. ONR has supported the development of the laser from its beginning, experimenting with different lasing mediums (crystal or glass and gas or liquid columns) as well as techniques such as the free electron laser.



The first high energy electron beam stabilized carbon monoxide electric discharge lasers (CO EDL) were developed at the Northrop Research and Technology Center with support from ONR in 1968. At the time, it was the most efficient directly excited laser system resulting in electron guns and



From the 1970's to the present, scientific investigators of ONR have been using environmental satellites such as the geosynchronous satellite shown here. The spin-scan cameras on these satellites produce imagery of the earth, its oceans, and clouds. ONR has been using remote sensing techniques for many years. Back in the 1950's, ONR studied shallow water currents from photographs taken by cameras suspended from helium-filled balloons. Today ONR is involved with remote sensing research conducted from manned space crafts equipped with instruments capable of recording oceanographic data.



This 1974 photograph shows Professor Nicholas Bloembergen beside his Nd-Yag Picosecond pulse laser apparatus in his Harvard University Laboratory. Professor Bloembergen uses this apparatus in nonlinear optical experiments, which he has been conducting for 40 years with the support of the Office of Naval Research.



The lithium-thionyl chloride battery is the highest energy density battery available commercially. The use of this battery system by the Navy is increasing because of its high power to weight and volume ratio. The discovery and early development of this battery system was supported by ONR in the early 1970's. The research was performed by Drs. James Auborn and Adam Heller of the GTE Laboratories.

Science And The Military Mission

EDWARD TELLER

*Lawrence Livermore Laboratory
Delivered at ONR's 30th Anniversary*

One of the most spectacular accomplishments of science in the Navy was the contribution of A. A. Michelson to an exceedingly important area of pure science. Michelson, as you may recall, was a Naval Officer and a graduate of the U.S. Naval Academy. In work carried out at Annapolis, he showed that the velocity of light relative to the earth is independent of the motion of the earth. A few hundred years ago, this result would have been interpreted as proof that Aristotle was right after all and that the earth cannot be moving. At the time, it began to be realized that the deepest conceptual changes concerning motion must follow in his discovery. From this realization, a search for the nature of these changes followed, eventually resulting in the evolution of Einstein's relativity theory.

This remarkable accomplishment (which had, of course, no immediate practical consequences) I might balance with a counter example. In 1939, Enrico Fermi, recently arrived in this country, tried to persuade senior Navy officials of the importance of the application of nuclear physics to the production of what we now call atomic bombs. Unfortunately, he did not succeed because there was no technically competent office in the Navy to consider such matters — one might speculate how much history could have been changed had ONR existed in 1939.

Just after the Second World War when ONR was established, one of its first actions was to support science at universities. In doing this, ONR reinforced and augmented the old and truly important linkage of the military with science. Today, after a very destructive period of antimilitary, antitechnological, and even antiscientific movements in our universities, we can fully appreciate how important it was on the part of the Navy to have set the goal of enhancing and maintaining cooperation with our scientists at an early stage and maintaining it throughout the turbulent period of the 1960's through the agency of ONR.

Now to the ominous problem that is facing us at present. We have heard guarded statements about the United States still having superiority along the ocean routes connecting the mainland of the United States with Hawaii, Alaska, and Europe. The implication is clear. We have lost the power to guarantee the freedom of the oceans with the exception of the limited regions most important to ourselves and our closest allies. The future is even more frightening. How long can we maintain superiority even in this relatively small portion of the deep seas?

Why have we lost this power, and what can be done to revive it? The outlook is not good. An antimilitary trend has penetrated deeply into the Congress of the United States. As a result of this, our defense budget has steadily decreased over the past decade in relation to that of the Soviet Union. As long as the Soviet Union can outspend us in military respects (even though their economy is much less strong than ours), it will be hard to avoid the menace of Russian superiority, which may soon become overwhelming. In this situation, the quality of our work becomes particularly important, and this in turn is directly related to our scientific effort. It is not easy to be optimistic about the potential for widespread acceleration of a new and strong coupling between the military and the scientific community through military oriented scientific and technology programs. One of the primary problems is excessive secrecy in defense, which repels the scientist. In Russia, such considerations make less of a difference, because the Russian scientist has less of a free choice, partially because secrecy and other restrictions will be with him whether or not his work is connected with defense. As an aside, it should be noted that in the debates regarding levels of defense spending in the United States the true facts of Soviet superiority are suppressed and withheld not only from our scientific community but from the population at large!

It is remarkable that the United States has managed to keep ahead of the Soviet Union in exactly one technical field: electronics. This is a field in which official secrecy has hardly been applied. One may therefore make a good empirical case that in our society, secrecy is counterproductive.

What may be lacking is the thoroughgoing application of our magnificent electronics industry (which includes television, hand-held computers, and everything in between) to problems of defense. In this respect, the Navy and also ONR are engaged in important research. One may mention as an example the recent and most significant investigations on procedures in which many small computers may be brought together into a flexible system that is likely to outpace the performance of the big computers. Remotely Navigated Vehicles (RNV'S) may be even more important. An RNV could be an unmanned ship or a torpedo-like object or even an instrument carrier launched exclusively for purposes of reconnaissance. RNV's could dive under the water, swim on the surface, rise into the air, or even "walk" both on water and land at respectable speeds. The absence of a crew would not only result in saving human lives but it may also stop the trend toward ever-more expensive and therefore ever fewer fighting units.

What I mentioned above are merely examples of applied science and advanced technology. It is indeed impossible to attempt a complete enumeration of relevant developments. But as an additional example one must refer to lasers, which indeed have already been mentioned in connection with missile defense. But the Navy should not neglect the use of lasers underwater. Even though the range in water is limited, the limit can be somewhat extended by increased intensity. Considering the ever greater importance of submarines, the lasers that may help in their detection cannot be disregarded.

Many years ago, a captain by the name of Hyman Rickover came to visit me in Los

Alamos. He introduced himself as a DOPE. When I heard the introduction, I did not realize that the word consisted exclusively of capital letters signifying "Doctor of Pile Engineering." Such doctorates were awarded to students at Oak Ridge National Laboratory. What was news in the late 1940's is history now. Nuclear reactors made true submarines possible. I regret that these submarines (which I, of course, supported from the time I first met Rickover) are not yet produced in a much greater variety. As just one example, one may mention submarine oil tankers, which could carry 200,000 tons of oil below the Arctic ice cap from Alaska into the Pacific or into the Atlantic. Such submarines might compete with pipelines. They might be more flexible than pipelines; and what is most important, they could be used in times of war to maintain deliveries of heavy and massive materials to our forces fighting overseas. In fact, in a truly serious conflict, submarines might be the only ships to survive in the long run. The Navy, which has given real help in the past to our maritime fleet in order to have ships available in time of war, may do well to participate in the development of these big submarines.

The project I have mentioned is just one aspect of submarine warfare. Another possibly more important aspect is the whole science and technology of the delectability of submarines. This area is perhaps a deeper secret than any other branch of military technology. In this case, too, secrecy has worked to our disadvantage. Not only has it impeded genuine scientific and technical progress, it may result in an illusion of security after security may in fact have been lost.

Apart from the areas of development that I have just mentioned, I would like to add a little more on the general subject of oceanography. We should not consider the vast expanse of our globe covered by water only as a means to get from one place to another. We know that the bottom of the ocean abounds in valuable materials like oil and manganese nodules, to mention only two examples. We have reason to believe that the ocean holds part of the key to the problem of how to feed 7 billion people by the end of this century. Surely this cannot be done by Stone Age methods of pure ex-

ploitation. The modern procedure of cultivation will certainly be needed.

None of this can be accomplished without international cooperation, and it will not occur without some international controversy. All this means that the role of the Navy will in the future be immeasurably greater than it was in the past. The freedom of the seas used to mean only the freedom to come and go. In the future, freedom of the seas will stand for guarding and developing the riches of the oceans, which, indeed, are a great common heritage of all mankind.

What we have to do, we are barely beginning to understand. I have mentioned some technical means and some general goals. None of this can be truly accomplished without spending much money, and none of it can be accomplished without spending it in an intelligent and selective manner. The farther we look into the future, the more obvious it will become that without a thorough use of science and technology the Navy cannot accomplish its tremendous mission. The Office of Naval Research must now turn from contemplation of three decades of illustrious accomplishment to the challenge of the future--our survival as a nation.

FORTY YEARS

At twenty years of age, the will reigns; at thirty, the wit; and at forty the judgement.

Benjamin Franklin, Poor Richard's Almanac, 1758



The Sidewinder missile provides fighter aircraft increased effectiveness in their interceptor role. Over the period of its development, ONR has been an influential force. The missile is known among fighter pilots as their "right-hand weapon." Early work in the 1980's refined AIM-9M Countercountermeasures (CCM) algorithms. The photograph shows a technician working on a Sidewinder AIM-9M at a repair station, Naval Weapons Center, China Lake, California.



Image of a bipolar transistor obtained with a cryogenic scanning acoustic microscope in 1983. The aluminum conductor strips are about two millionths of a meter wide. The microscope can be compared to a very small scanning sonar with a frequency several million times that of sonar. Certain properties of materials or component parts which cannot be seen when using the reflection of light with a conventional microscope, can be observed by the reflection of sound. This acoustic microscope can be used to inspect small details of electronic components such as chips because its resolution is better than an optical microscope. ONR supported the basic research on this microscope, which became ready for commercial application in 1986.

Marginal Ice Zone Experiment (MIZEX) in 1984 was the most extensive environmental field study ever undertaken of the Arctic region. Funded by ONR, MIZEX was designed as a drifting experiment covering approximately 125 square miles of the east Greenland Sea. Scientists from ten nations participated in this study of remote sensing, meteorology, ice dynamics, oceanography, biology, modeling, and acoustics.



ONR designed and built the vertical profiler at its Naval Ocean Research and Development Activity, Bay St. Louis, Mississippi. The profiler is a general purpose oceanographic and acoustic sensor system which can profile up to and through the air-seas interface, which makes it ideal for measurements in this high-energy exchange. With its internal timing controls, the profiler can be preprogrammed to descend and ascend at specified times. The record diving depth is 1,000 meters, and it uses lithium battery packs to drive the internal ballasting pump.



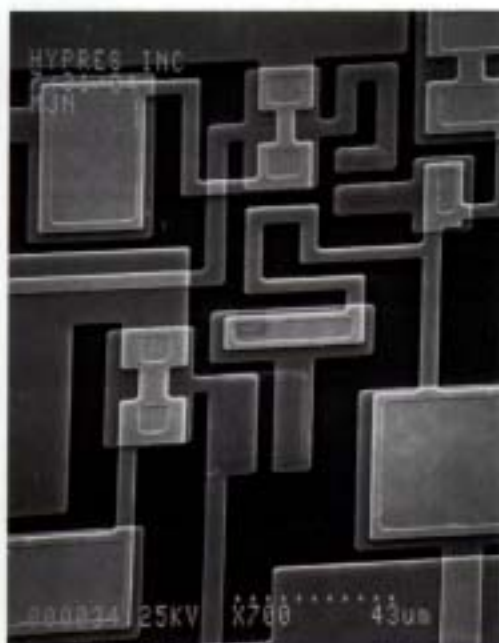


Dr. Graham Hubler of Naval Research Laboratory examines the rolling elements of a J-79 bearing during ion implantation with chromium ions. The glow is caused by fluorescence of highly excited atoms sputtered from the surface of the 150-keV chromium ion beam. Ion implantation consists of injecting atoms of any desired element electronically into the surface layer of a metal, producing an intimate alloy without the sharp interface characteristics of a coating. This technique can make wear-resistant parts that increase manifold the lifetime of the engines or systems in which they are used.

Jason, the remotely operated robot with its high-quality cameras and advanced manipulators, was developed by Dr. Robert Ballard at the Woods Hole Oceanographic Institution with ONR funding. The testing expedition of Jason and Argo, its camera platform, began in 1985 with the discovery of the wreck RMS Titanic at a depth of 3,795 meters in the North Atlantic. Later, complicated testing maneuvers were done successfully within the wreck. This search and survey system can work in depths to 20,000 feet and is equipped with up to three 35mm color cameras each having 4000 feet of film.



Two Naval Research Laboratory solar experiments were flown on the Space Shuttle's Spacelab 2 in 1985. Shown here is the high resolution telescope and spectrograph (HRTS) which was designed and built by the Naval Research Laboratory to measure the ultraviolet radiation from the sun. NRL astrophysicist Dr. John David Bartoe was aboard Spacelab 2 as a payload specialist.



Josephson technology time domain reflectometer circuit built by HYPRES, Inc. of Elmsford, New York, for ONR. The circuit consists of all-niobium Josephson junctions, interferometers (SQUIDS), capacitors, resistors, inductors and ultra-wide bandwidth transmission lines. Shown are two pulse generators producing seven picoseconds duration pulses and a sampling gate. The circuit, which is magnified 700 times, has minimum features of five micrometers. This circuit is an example of very complex superconducting integrated circuit performing memory, logic, and other function.



Early Days Of Quantum Electronics And The Office Of Naval Research

Dr. Charles H. Townes
University of California, Berkeley
Presented at ONR's 40th Anniversary

It is an honor and a great pleasure for me to participate in this occasion celebrating ONR, which has contributed so much and so effectively to the nation. It has also been a great help to many of us here individually. I want to talk about the field of quantum electronics — the field of masers, lasers, atomic clocks, and a good fraction of modern optics. In a way, this is just a vignette of a particular area, but on the other hand it will illustrate some of what is involved in the cultivation of research and of technology, and the operational relations between government, universities and industry.

During World War II many scientists, including particularly many of my physicist friends, were much involved in the war effort. As a result, they learned a great deal about electronics, radar, and microwaves which they would not have otherwise known. And as they returned to the universities, this background led to a great burst of fundamental discoveries and developments. For example, there was nuclear magnetic resonance, linear accelerators, the development of radio astronomy, paramagnetic resonance, and microwave spectroscopy. Many of these developments were close to my own field of interest. I became interested in the possibilities of microwave spectroscopy working on shortwave radar ($1\frac{1}{4}$ centimeters wavelength) during the latter part of the war. I was then at Bell Telephone Laboratories, and set up shop trying to see what might be done to exploit these new possibilities. The work went well. Initially, microwave spectroscopy was strong particularly in industry — RCA also had a strong group, so did Westinghouse and General Electric. Columbia University had been working on magnetrons during the war so they had equipment and were doing something in the field, although not quite as much as these three industrial laboratories.

The new field was very rich scientifically; but pretty soon industry lost interest. I

was at Bell Telephone Laboratories, which was beautifully supportive of me, but not interested in expanding the field. This made attractive a proposal to move to Columbia University where there was good equipment and many people interested in the field. In any case, I had always enjoyed universities and decided to go there to Columbia's Radiation Laboratory which was supported by the Joint Services Electronics program, of which, of course, ONR was an important part.

The primary applied purpose of the Columbia Radiation Laboratory was to develop magnetrons, particularly to push magnetron design towards the shorter wavelength region. But the Joint Services had the foresight to see that to really expand that field, one also needed a broad horizon. So the Columbia laboratory had a charter to work broadly and extensively in high-frequency research.

About two years after my association with Columbia, the Navy asked me if I would chair a committee to examine the possibilities of developing better millimeter wave sources. I never knew who initiated the idea, but Moe Long was involved and Paul Johnson was the contact person. I enjoyed working with them in setting up such a committee. I of course included electrical engineers—John Pierce of Bell Laboratories, Jerry Shepherd who was then at Minnesota, and Marvin Chodorow of Stanford, but also people in surrounding field. We realized that one must look rather broadly at the field, and I persuaded John Strong, a famous infrared experimentalist of that era, to join us as well as John Daunt who was in cryogenics, and several others in fields which might be pertinent. We were to review the ONR program and think about ways in which millimeter waves might be generated better — or at all, because it was very difficult in those days — and to visit the places where there was ongoing research and try to encourage development of the

field. We met and had enjoyable and interesting interactions with many researchers in the field.

After about a year, I was frankly a little discouraged. We had explored all sorts of ideas. It became clear that the concentration of energy required in order to produce oscillations at very short wavelengths and the dimensional integrity one had to maintain in a device which could probably not be much larger than the wavelength were pushing the limits of practicality. Just before one of our meetings, I got up early (to which I was addicted because I had young children), wandered out into Franklin Park in Washington, and sat down to think what really were the possibilities. What must really be done to extend oscillators substantially towards shorter wavelengths? The background of my thoughts included the fact that at Bell Telephone Laboratories I had argued and written a memo that molecules and atoms might some day produce circuit elements — that they were in fact the natural circuit elements for the very short wavelength region. Furthermore, L. I. Rabi of Columbia already had suggested atoms as possible frequency standards for atomic clocks — essentially another "circuit element" type of use. I did not originally imagine good generation from atoms or molecules — in fact I specifically said in my memo that one could not get very much intensity from molecule because the intensity was limited by the second law of thermodynamics. Nevertheless, as I sat on the park bench struggling with what we must do, I decided that somehow one had to find ways of using atoms and molecules. Suddenly, it occurred to me how that might be done. While it was not overt, I'm sure my thoughts must have been influenced by a fairly recent paper from Harvard on inverted populations and negative temperatures. In any case, I recognized that, at least in principle, if we get rid of equilibrium thermodynamics, we don't have to obey the second law.

Then one can achieve amplification and an indefinite amount of power. Probably because I was in a laboratory where molecular beams were being done and I knew all the parameters involved, I quickly worked out what might be done by beam-type separation of states and found that, yes, it was practical. One could perhaps do it. And I had to call another idea I had recently heard about—quadruple focusing of beams to achieve very high intensities, which had recently been demonstrated by Professor Paul of Bonn, Germany. It did not seem an easy experiment to produce amplification and oscillation with molecules, and we did not start on it until four or five months later. I told many people about it, and they said, "Um-um, yes, interesting," but nobody was very excited about it, perhaps because the amount of power I proposed to get was very small, but I believe more likely because few people were oriented towards recognizing its potentialities. I had originally worked out a system for the far infrared because I had wanted to push down to very short wavelengths in order to do spectroscopy. That was my drive. The Navy was interested in millimeter wave generation. But I decided it best to retreat to the centimeter region because there we had techniques which made the work easier and I could try out the idea there. Jim Gordon was brave enough to undertake it as a Ph.D. thesis. In addition, I enlisted Herb Zeiger, a postdoctoral man from Rabi's group who was familiar with molecular beams, to help us out. After three years, the normal gestation time for a student thesis, sure enough Jim Gordon had built a maser that worked. It created appreciable interest but its potential was still poorly understood. One of my good scientific friends said, "Well, I am glad that you got that going; now you can get back to some of the spectroscopy you were doing, which is really important!" But I was excited about the possibilities I thought I saw.

I have given this history in some detail to indicate the importance of the network of scientists—scientists with different habits of mind, different interests, different kinds of backgrounds and available resources. Our scientific community is a network, and interactions in this network are impor-

tant for rapid innovation. Secondly, it should be clear that the whole field came out of microwave spectroscopy. That conclusion is reinforced by recognizing that somewhat similar ideas arose, with different degrees of completeness and orientation, in two other places independently. One was the University of Maryland where Joe Weber, another microwave spectroscopist, proposed stimulated emission as an amplifying mechanism in ammonia gas, but without a resonator or feedback. This proposal had some technical problems but nevertheless recognized the possibility of coherent amplification. Another was in Moscow where Prokhorov and Basov were engaged in microwave spectroscopy. Thus, there were three independent starts in the field, all coming out of microwave spectroscopy. Clearly that was the critical field. Note also that it was a field of no clear interest to industry and more or less abandoned by industry for that reason, but sponsored in universities because it was producing physics. Yet it was a field of "pure" science which generated the maser and almost all its initial contributions.

Now I want to mention another personal association with the Navy. In 1956, when I came back from Europe and Japan after my sabbatical leave, the Bell Laboratories had made the first paramagnetic three-level system really go, based on Bloembergen's idea. I was eager to produce some good amplifiers to do some radio astronomy. NRL had an excellent program in radio astronomy built up by John Hagen. Cornell Mayer was head of it at that time. So I went to see Cornell Mayer, asking could we collaborate and use his telescope on top of the NRL building; he was glad to accept. At Columbia, we then built a paramagnetic amplifier. I think the first maser amplifier to do useful work was the one we put in place on the NRL antenna. With it, we immediately got an improvement in the signal to noise over what had been previously available by a factor of about 15. We reconfirmed Cornell Mayer's measurement that Venus was, in fact, very hot, along with other astronomical measurements.

Maser amplifiers also stimulated much other work. Walter Higa, in talking with me about the improvement in sensitivity,

asked if a parametric amplifier might not in principle be very noise free since it, like the maser, was free of electron charge noise. That hadn't occurred to me but after a little thought I agreed; paramagnetic amplifiers would also be low noise. Suddenly, people began to get interested in parametric amplifiers. By now, they have replaced masers except for the very most sensitive amplifiers. This is another sample of the complex pattern of interaction within the scientific community, in both pure and applied work.

Now, what about lasers? The laser is, of course, the same idea pushed to shorter wavelengths. However, it has characteristics which are different enough that it is almost a separate field. I had originally wanted to get into the short wavelength range and initially planned for a system in the far infrared. The microwave region was, in essence, a temporary diversion though a valuable one. I kept thinking about eventually pushing into the submillimeter range and then to as short a wavelength as one could go. But I was busy with the maser and waiting for the right idea to turn up. It's important historically to indicate to you the lack of orientation within even the maser community towards this field of short wavelengths. There was almost no one thinking of moving into the optical or short infrared region. I know of no written material on this until the summer of 1957, when there was an Air Force study on what the Air Force might be doing in the next 25 years. I was on that committee, and we put into the committee report that the Air Force should envisage work to short wavelength at least as far as the mid-infrared with maser-like techniques. But I had not yet had a neat idea of how to do it. So by the fall of 1957, again out of frustration that it had not come along, the same sense of frustration I had before the maser idea came along, I said to myself, "I still don't see how to do this well. I can certainly get down to the far infrared but how can we go much shorter? I better take some time now and really think seriously about it." It was thus in reviewing the possibilities in my mind and on paper that I suddenly realized it is just as easy to go into the optical region as into the far infrared, because the equations

show that the number of excited molecules or atoms required is essentially the same. The resonator, while still rather amorphous in style, seemed about equally lossy in both regions. The problem was then a resonator of appropriate style which could isolate the different modes. I had some partial ideas of a cavity with big holes in it, to eliminate some modes, but the more complete answer to this probably came a little later.

I was at the time consulting at Bell Telephone Laboratories, and discussed the whole proposition with Art Schawlow, who had worked closely with me at Columbia and with whom of course I had easy conversations. Art said he was quite interested in the problem also, and we agreed to pool our efforts. Rather soon he proposed the idea of using simply two parallel mirrors as a cavity. That would eliminate more than my holes in the cavities would do. We worked on this approach and could easily show that, in fact, one could isolate a single mode in that type of cavity. This eventually resulted in our paper, discussing the striking properties of such a system and a few particular systems where all the parameters were known well enough that we could show theoretically that they really had to work. Alkali atoms were a good material in this respect, because these properties were well enough known to allow a rather certain calculation of parameters and a convincing conclusion that they could work. Other systems we suggested such as crystalline materials looked promising but these properties were less well known.

Shortly after our paper appeared, on what we then called an optical maser because we thought logically one should talk about a whole series such as microwave, IR, optical or OV masers, I was approached by Irving Rowe from the New York office of ONR who asked me if I would organize a conference in this field. The theoretical paper on optical masers or lasers had been published, and work on masers was growing like mad. The maser field was popular enough that the *Physical Review* had printed an editorial statement that it would not publish any more papers on masers because they were getting flooded by them. That was only a stop gap measure, because pretty soon lasers came along and they were flooded

again! But the next significant step was that ONR recognized it was time to really have an assessment of the field, and to get everybody together to stimulate its most efficient growth. I accepted Irving Rowe's invitation to organize a conference, with expenses and sponsorship courtesy of ONR.

Let us look back again now, and ask whether an industrial research administrator of the early 1950's would have decided to promote this field. Even the best of industry's research directors would not likely foresee, and clearly didn't foresee the future of this field. It was impossible to do so. Very frequently decisions in industry go against supporting long — range research, because of the great difficulty in predicting its outcome. However, as long as such research is supported elsewhere in the nation I think we are all right. But there must also be a healthy and strong interaction back and forth between pure and applied laboratories. For the field of quantum electronics, industry was ready to move when the field began to develop, and since that time has done a very outstanding job. So far as the Navy is concerned, how did the Navy know to support such work? The Navy didn't know the specifics but had the wisdom to encourage an active field where there were good people working and where new ideas were coming along, realizing that at some point important contacts with applications were likely. The Navy could not possibly have predicted that this might help them in communication with submarines, or new kinds of gyros, or reliable fiber optics communications, or guidance and ranging, or in data handling. A field like microwave spectroscopy, that is the interaction between microwave and molecules, must seem like an improbable choice for developing a new gyro. Industry faces the same problem. In the civilian field, lasers have had an enormous impact now on communications, information recording, materials processing, cutting, welding, hardening surfaces, on surveying, on surgery. There are few fields that this development has not touched. That is to be expected for it is a combination of optics and electronics—two important fields. Both are very widespread and such a combination is likely to touch

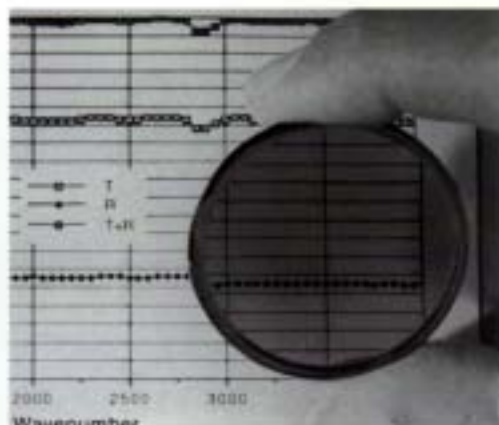
almost any field of science or applied science. But it was difficult to foresee in the beginning.

Looking back on all of this, that is, the idea of the laser or the maser, can make them seem remarkably simple. That's one of the characteristics and beauties of science; once you understand something, it is often really simple, and we can go on from there to further progress.

FIFTY YEARS

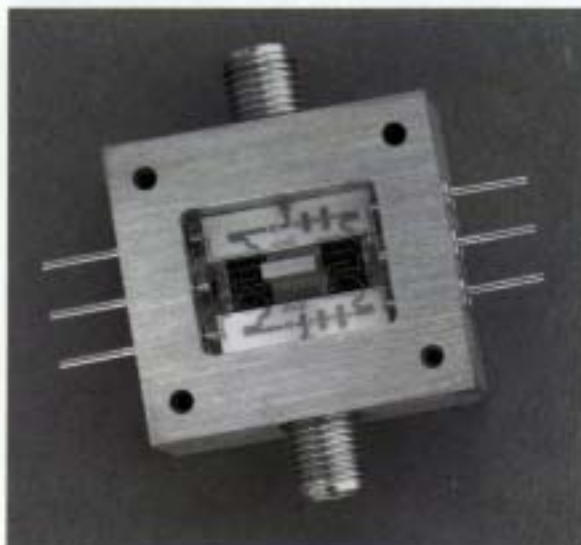
No wise man ever wished to be younger.

Jonathan Swift, *Thoughts on Various Subjects*, 1726



Diamond-coated domes for high speed missile which were developed with ONR funding will provide the infrared transparency needed for guidance systems and open the door to the development of even higher speed missiles. In 1991 through a process known as chemical vapor deposition, ONR was able to drastically improve the making of synthetic diamonds in quantity. Navy application of synthetic diamonds include long-life bearing in engines and rotating machinery on ships; they offer ideal protection for optical fibers and space-based radiation sensors; and they could make faster electronic chips that operate at high temperatures.

ONR recently developed a miniature microwave active filter. Circuit miniaturization has been thwarted by the inability to successfully reduce the size of the microwave filters. A prototype of these filters measures a fraction of an inch in length. The new scheme reduces the size of microwave systems and eliminates the possibility of feedback and maintains clarity.



This helmet mounted system developed by ONR and called PowerScene demonstrated its ability to receive digital imagery from a satellite and display it in real-time. The system is being used for intelligence as well as for mission preview, rehearsal and planning.



The Head Island Experiment measured global ocean warming by long-range sound propagation. On January 26, 1991 coded signals were transmitted from Heard Island in the Indian Ocean to an international coalition of nine listening stations. The underwater acoustic signal sent from the southern Indian Ocean was received 9,970 miles away on the east and west coasts of the United States. Professor Walter Munk of Scripps Institution of Oceanography conducted the experiment for ONR. Global ocean warming can be determined by comparing the change in sound speeds over these long ranges over several years time and applying the principle that a 5 m/s sound speed increase indicates an average basin-wide temperature increase of 1 degree centigrade. The experiment explores also the feasibility of long-range ocean acoustics for communication, antisubmarine warfare, and monitoring global ocean warming.



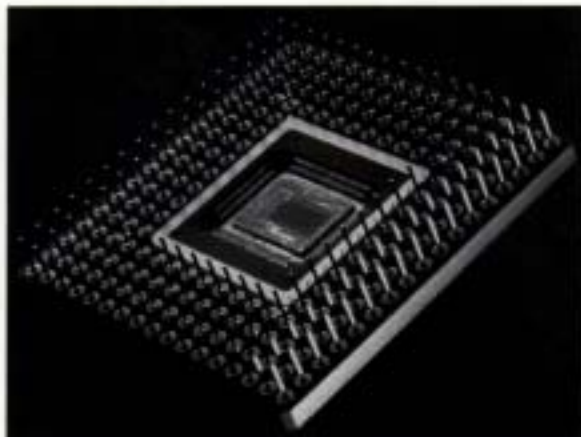
Hull fouling by crusts, slimes, and hard foulers like barnacles cost the Navy and Marine Corps more than \$3 billion annually in antifouling activities. Added to that bill are the costs of increased fuel consumption, reduced ship speeds, and overall reduced fleet readiness. To reverse the course, ONR's program in Molecular Biology of Marine Organisms broke with a long established practice of studying fouling organisms and instead undertook the study of the molecular processes and materials involved in marine bioadhesion. While myriad organisms are involved in biofouling, their adhesive properties have a common molecular basis, and investigations at that level are directed toward the development of a long-term and environmentally sound biofouling solution, which will prevent fouling and its costly removal.



ONR developed recently AirMet 100 Ultra-High Strength Steel under the Navy's exploratory development program. Immediate use this durable, strong, and corrosion resistant steel is in the landing gear on the F/A-18 E/F aircraft. The steel will result in significant weight and life cycle cost savings. Future applications include the F/A-18 EF horizontal stabilizer (tail) spindles, V-22 swashplate actuator component, F-14 wing pivot pins, helicopter components, and armor, which is being jointly supported by Army Science and Technology. Improved fatigue, fracture, and environmental resistance of this material will benefit the Navy.



Duck '94, The largest near-shore field experiment, took place at the U.S. Army Corps of Engineers facility in Duck, North Carolina, with funding from ONR. Conducted between July and October 1994, the experiment involved close to 100 scientists, engineers and students representing 15 universities. Investigators measured ambient acoustic noise in the surf zone, sea mine migration and burial, sediment accretion and erosion, bottom morphology changes from bars to ripples, wave interaction, along-shore currents, sediment movement, and turbulence. Program data has already been used to support related research in surface ship and submarine acoustics, amphibious assault and special operations, and the development of shallow water surveillance technology.



The 80100 computer chip developed in 1992 by Intel Corporation of Santa Clara, California, with ONR funding represents a new generation of intelligent, high-performance chips based on the neural network computational paradigm. The new technology is a promising approach toward building intelligent machines that mimic hearing, seeing and thinking. The chip is amazingly quick at recognizing handwriting, identifying military targets, and other tasks that are impossible for conventional chips. By employing a large number of processing elements that operate in parallel, the 80100 performs 20 billion interconnection operations per second.



RADM Marc Pelaez
Chief of Naval Research



Dr. Fred Saalfeld
Deputy Chief of Naval Research and
Technical Director, ONR

Increasing world instability and uncertainty requires the Department of the Navy to prepare for the *Navy after Next* with maximum flexibility and capability. Within the boundaries of fiscal realities and constrained resources, we must focus our visions to achieve an unquestionable technological edge enabling the Sailors and Marines of the future to win anywhere, anytime. Technological superiority can only prevail through a far-sighted and innovative strategy such as is outlined in the attached White Paper, "*The Navy after Next: A Technology Vision of the Future.*"

Some may say that it is difficult to be far-sighted and innovative when a specific threat is not known. Only by making the right strategic science and technology choices now, about which new capabilities are likely to prevail regardless of the threat, will we be able to dominate any battlespace of the future.

Developing new technologies and incorporating them in naval systems is typically an evolutionary, rather than revolutionary, process. Historically, we held the balance of power because we had bigger and better weapons, and we had more of them. Today, we are no longer the sole exploiters of technology. Off-the-shelf technological innovations become rapidly available to any and every country capable of paying for them. U.S. military superiority in the future will depend not so much on out-gunning our enemies, as much as out-smarting them. The victor of information technology battles will likely be the victor in wars of the future. Accordingly, a clear center of gravity for our vision of the Navy after Next is advanced and innovative surveillance capabilities. Advanced information technologies coupled with new precision strike capabilities will be the heart of the warrior's edge in the Navy after Next.

This document, targeted at the Navy and Marine Corps of 2020, was developed to look at tomorrow's technological possibilities based on the realities of today. It is not all inclusive, but rather a skeleton on which to build. We don't know with certainty which technologies will mature or which will prove to be most important, but we can see significant trends. Some technologies are on a steady track and will likely be available sooner than 2020. Others may not be available until the 2030's. Nothing in this document defies the laws of physics, however, achieving the capabilities we desire will require science and technology to push beyond the boundaries of our current understanding.

This is a time of great change for the Department of the Navy and our nation. But along with this change comes opportunity. Now is the time for us to be open minded and think outside the boundaries of all things conventional. This is our opportunity to put a stake in the ground to define the *Navy after Next* and set our vision of the future.

THE NAVY AFTER NEXT

A TECHNOLOGY VISION OF THE FUTURE

Overview

The *Navy After Next* will put to sea in about 2020 and will exploit emerging knowledge and materials now within sight of the technology horizon. The lead time from concept to deployment—even with compressed integrated design and manufacture—will require specific investments during the six-year plan of PR-97. Although operational goals and enduring naval missions will retain their form, the *Navy After Next* will be barely recognizable in form and greatly enhanced in capability.

The Enduring Naval Mission

The Navy and Marine Corps mission will continue to be preparation of the battlespace for follow-on land-based Army and Air Force actions and assured delivery of quantities of materiel and resources that can only move by sea. Because of this First-on-The-Scene/Fight-Our-Way-In and the closely related "Joint Presence" on the Edge-of-War role, the *Navy After Next* may have to operate initially without joint or allied weapons or surveillance support. Information will be gathered and moved by space systems or by organic autonomous vehicles operating throughout the sea-air-land battlespace. Absolute dominance in information warfare will be essential in achieving the operational missions of the *Navy After Next*. If our deterrent presence fails, weapons will be delivered precisely from the sea to targets hundreds of miles inland and threats from manned or autonomous enemy systems will be neutralized. Beyond the progress needed to simply match the growth in the threats available to any adversary with the will and money, the *Navy After Next* will have to meet heightened expectations for minimums in cost of acquisition and operation, casualties and collateral damage.

Expanded Capabilities will be Derived from New Science and Technology

This vision for the *Navy after Next* is a snapshot into the future taken from a cam-

era aimed and focused in 1995. What is portrayed, is a Navy with significantly expanded capabilities in four critical operational domains: **command, control, and surveillance; battlespace dominance; power projection; and force sustainment**. This white paper provides today's vision of new or expanded capabilities in each of these domains and selected cross-cutting capabilities that will impact all four of these operational domains.

Achieving the vision for the *Navy after Next* requires the solution of many difficult science and technology (S&T) problems. Progress in S&T typically proceeds linearly and orderly given sustaining investment. While most of the visionary projections for naval capabilities in 2020 described in this paper assume this linear advancement in S&T, a number of "stretches" requiring important S&T breakthroughs are also interspersed.

Three critical bottleneck areas are likely to govern the ability to achieve our vision for the *Navy after Next*—software development, microelectronics, and novel materials. Accelerated progress in each of these areas is essential since each is rate limiting on progress across all other areas. Revolutionary innovation will grow out of Navy S&T in partnership with the Advanced Research Projects Agency and the other Services, while evolutionary, dual-use developments will be driven by industry's economic interests.

Software is the "Achilles heel" of the information revolution underpinning future Naval warfighting capabilities and systems. As computers become more compact, more powerful, more affordable, and ubiquitous, they become candidates to perform ever more complex and impressive tasks, requiring ever more complex and voluminous software. Advanced automatic capabilities involving autonomous vehicles, intelligent decision aids, synthetic environments, and all-source multi-media data fusion represent only a small sampling of the software-intensive systems that can plausibly revolutionize naval warfighting and crisis response.

However, the technology to produce, maintain, and upgrade complex software systems remains primitive. Software-induced failures in complex military and commercial systems are all too frequent. As the Navy comes to depend more on automated systems to accomplish its missions, it will become less and less able to tolerate software failures. Research to date has not unearthed any silver bullets for the software crisis. Dramatic advances in automation of future Naval systems and capabilities depend upon achieving substantial new insights into the process of designing and developing complex software systems.

The Office of Naval Research (ONR) vision for the *Navy after Next* does not violate any fundamental laws of nature. It does extrapolate from what we know today and what we believe we will know tomorrow. Knowledge must be nurtured and sustained. Advances will not occur merely as a function of time. ONR is eager to build upon its rich half century history of catalyzing, nurturing and promoting the highest quality S&T for the benefit of the *Navy after Next*.

Advanced electronics is another underlying enabling technology critical to the warfighting capability of the *Navy after Next*. Future naval systems will be completely dependent on advanced electronics to accomplish their mission. In the last three decades there has been explosive growth in electronics, doubling its density and performance every three years at reduced costs. With continued S&T support these advances are envisioned to continue unabated for the foreseeable future. Several areas of research, such as super-high density memories, nanoscale electronics, single electron transistors, and spin transistors will result in four to five orders of magnitude increase in device and memory densities. These super dense electronic chips will enable the highly compact storage of massive amounts of data (global terrain maps, target data bases, etc.) allowing information processors and digital computers to run at lighting speed. Multispectral, infrared—to

microwave—sensors will enable the operation of surveillance systems to detect targets and missile seekers to home-in on targets during day/night and all weather operations. Wide bandgap semiconductors will enable multifunctional radar systems to operate in different bands with just one system, thus reducing size and weight. Evolutionary and revolutionarily advances in electronics is the critical enabling technology for significantly enhanced Navy warfighting capability.

Advanced materials development will enable a host of new design options and capabilities for naval platforms which will be affordable, flexibly manufactured and maintainable. Thick composites combined with advanced joining techniques will permit radical new platform designs. Composites embedded with sensors and actuators will bridge the information processing and mechanical fields making structures more controllable and survivable. These smart materials will also enable new continuous control surfaces for responsive vehicles. Metal and ceramic engines with composite bearings will operate at higher-temperatures and give more power per weight. Advanced high strength, high toughness steels will halve the weight of conventional steel structures. Corrosion resistant materials like titanium alloys and composites will lead to dependable piping with long life. Polymer coatings for vehicles will reduce drag and resist fouling. Perhaps the most striking advances in materials will come in manufacturing. Advanced algorithms and high speed parallel processors will model the actual near-atomic scale processes in sheet metal and will enable flexible manufacturing with virtually no waste products, saving billions annually. Parts, made from polymers and new hybrid materials, will be stored in "electronic warehouses" as computer algorithms. When replacement parts are needed at sea the "electronic part" specification will be downloaded by satellite and made aboard ship under laser control. This savings in inventory and small job manufacturing costs will be extraordinary.

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and what we believe we will know tomorrow. Knowledge must be nurtured and sustained. Advances will not occur merely as a function of time. ONR is eager to build upon its rich half century history of catalyzing, nurturing and promoting the highest quality S&T for the benefit of the Navy after Next.

Command, Control, and Surveillance (Information Warfare)

Assured information dominance is a prerequisite for conflict resolution in the Navy After Next. Achieving this future capability is essential. New sensor capabilities coupled with new delivery systems and a variety of autonomous platforms will provide a rich database for intelligent sensor fusing, information processing, and advanced intelligent displays. The warrior's window on the battlespace will be panoramic, multidimensional, complete, and user friendly.

- **High performance visual displays will provide virtual windows for teleoperation and easy/rapid assimilation of large amounts of information.** Large screen or individual optical projections will enable assimilation of large volumes of repositioned and real-time information to human operators. Intelligent interfaces will respond to hand or eye movements or to spoken requests to allow the user to specify the specific information desired at any moment while providing "artificial intelligence" assistance to direct the user's attention to threats or to evaluate alternative responses. Full-color (or hypercolor), flicker-free, high resolution solid-state volumetric displays will immerse operators in 3-D tactical scenes which synthesize space-based, AUV, and surface-based sensor data into a common visualization. Ordinary visual "ports" would be unnecessary and less useful than one that presents an all-weather, day/night picture complete with signals and target identification. Teleoperation and computer aided monitoring will reduce crew size requirements to one-tenth current levels.

- **Battlefield surveillance will be provided by ship launched platforms.** These small platforms will carry miniaturized versions of the same advanced sensors that conventional satellites carry — radars, altimeters, scatterometers, communications, weapons control, and hyperspectral imagers — for all-weather intelligence gathering. This capability will provide the key in accelerating the pace of the conflict to our advantage.
- **Information will flow through a seamless land/sea/space network with warfighting survivability.** Proliferated, cross-linked mid-altitude satellites using robust waveforms with embedded navigation information will be linked to land-based and undersea nodes to complete a seamless Global Information Web. Ad hoc links, message formats and data elements will be subsumed in a seamless adaptive structure allocating capacity to suit the commanders' instantaneous need and automatically route traffic around damaged nodes or jammed links. Autonomous flyers or amphibians will be available to augment capacity in high demand locations and times and to couple undersea elements to the "Web". High-power blue-green lasers operated with nonlinear control to ensure stability will make all coastal waters locally transparent. Data transfer requirements will be carefully matched to survivability requirements of the mission and all static data will be repositioned for on-board integration with real-time updates.
- **Autonomous air vehicles will provide local surveillance and targeting information to support maneuver and attack.** Sensors and communications elements that appear in space systems for maximum day-to-day global cost-effectiveness will be complemented by compatible systems on UAV's. Advances in microelectronics will enable a miniature aircraft to contain surveillance electronics (including IR sensors, processing electronics, and transmitters). Power requirements will be met by a combination of advanced solar cells, microwave conversion capabilities, and/or advanced fuel cells. Solar cells will supply all power

necessary to fly the miniature aircraft during the day. At night microwave energy would be beamed up to the aircraft and be converted to supply power for the motor and imaging electronics and transmission of the data back to the ship. Such as roving autonomous aircraft could fly continuously, day and night, for ship area surveillance or battlefield surveillance.

- **Multi-Spectral BioSensor Arrays will provide real-time, continuous, multi-spectral, wide or selected area monitoring and assessment of biological or chemical agents in air and/or water environments critical for battle space assessment or routine operations.** These assessments will be automated and conducted at remote locations for prolonged periods. Miniature, robust, addressable and expendable sensor arrays based on molecular biological principles will be capable of real-time detection of a broad range of biologies and chemical species. Sensors will assess bio/chemical signatures from platforms, detect CBW agents, monitor biological and chemical features of the water column or atmosphere, and provide online, real-time monitoring of ship-board systems (reactors, weapons systems, cooling systems, etc.). Sensor arrays will be addressable through fiber optic light emission or electro-optical coupling, require minimum power, deployable unattended for periods in excess of months and provide multiple data streams which can be addressed using neural nets and pattern recognition systems. These system will be used to detect chemical and biological features of the battle space for prediction purposes, used in clandestine operation on-board ROVs, AUVs or robots, and provide real-time information on system performance to operators. These systems will be tunable, expendable, inexpensive, modular and adaptable to a wide range of uses and environments. For example small, portable and expendable CBW detectors that operate in high RF/EMI fields either in air or water will provide rapid, real-time early detection of CBW agents that can ensure chemical and biological warfare

survivability for both combat personnel and civilians.

- **Distributed underwater acoustic networking will couple sensors of multiple varieties (acoustic, optical, weaponry, UUVs, etc.).** Networks will be deployed in any underwater region of interest and communicate via acoustic modems. The value of each individual sensor will be enhanced by the knowledge of its neighbor. The network will be "self-healing" so that loss of one node will not cripple the network; other nodes will assume the roles of the lost sensor. Information gathered by the network is relayed to a central control center and incorporated in a data assimilative model. Armed or unarmed networks may be deployed anywhere, and if armed, fire an autonomous weapon when necessary. The network breaks traditional constraints of temporal versus spatial sampling as the combination of UUVs and moored sensors will be able to sample at high resolution in both space and time. The network relays all information needed by the warfighter: bathymetry, acoustic conditions, currents, target locations, biological data, etc.

Battlespace Dominance

Battlespace dominance in the Navy After Next will incorporate new technologies in aerodynamics, smart structures, machine intelligence and sensors to provide the supremacy of air, surface, and subsurface platforms in the delivery of their ordnance. Common to the survivability of these platforms will be improved threat warning, self-defense systems, and physical maneuverability.

- **Unmanned high performance air vehicles will ensure airspace dominance.** The advantages of an unmanned air vehicle as a weapons delivery system are numerous. By taking the man out of the system, significant weight savings will be realized through the elimination of life support systems resulting in increased payload, range, loitering time, speed and agility (with the latter providing enhanced survivability against enemy air defenses). Further weight savings will be achieved by utilizing advanced compos-

ite structures. Agility will be enhanced via thrust vectoring. The escalating problem of pilot workload will be eliminated. Full automation and/or functional transfer to a shipboard control center will couple directly air, land and sea battlespaces. Guided by a combination of GPS, inertial navigation system and a shared satellite-based communication system, these vehicles will provide a new capability in force projection.

- **Employing the same technologies as in the surveillance systems, advanced threat warning systems will increase early warning/threat reaction time in all weather environments against all threats.** Improved sensors, integrated with real time decision aids will increase the ability of all platforms to effectively neutralize an enemy attack. Key among these advanced sensors will be the capability to reliably identify enemy targets beyond their firing range. This will allow employment of our weapons at maximum firing range and reduce close-in combat maneuvering.
- **Improved decision aids integrated with advanced self defense weapons will permit operators to react optimally to the threat presented.** Once launched, these weapons, incorporating conformal antennas with digital data links, will be updated by offboard computer-assisted fire control systems capable of maintaining lock on a target irrespective of the launch platform's attitude. These "unshakable" weapons will have a greatly increased lethality.
- **Advanced distributed fire control with elevated sensors/illuminators will provide over the horizon targeting capability.** Whether in area cruise missile defense or theater ballistic missile defense this capability will allow future ships to effectively protect the entire battlespace with minimum assets.
- **Combat agility, particularly with regard to aircraft, will be greatly enhanced.** Whether by vortex control or "warping" skin, future aircraft will have unmatched agility supremacy. Given the need to engage in close-in combat, the performance edge will be with our aircraft.

- **Fully autonomous vehicles will revolutionize mine countermeasures and amphibious operations.** Autonomous and remote-guided, robotic platforms and underwater autonomous vehicles will assume major burdens in war fighting. Among the new vehicles will be compact robots for underwater and amphibious operations. Operating in groups, these small autonomous platforms would find and neutralize mines (by carrying a charge), perform surveillance on the beach with optical imaging sensors, and indicate targets with lasers. These vehicles will have robust, dynamically stable locomotion on broken terrain and rapid responses to current shifts by applying principles of biomechanics. Sophisticated sensor and dextrous manipulation capabilities will enable these vehicles to perform maintenance in pipes and tanks and survey toxic laden terrain. Stealthy underwater vehicles, perhaps with efficient fish-like propulsion, will combine different movement systems for operation in the most turbulent conditions. Appendages on such UUVs will give new retrieval and mine countermeasures capabilities. For example, octopus-like unjointed limbs will wrap around their targets and be able to retrieve objects in the water without damage. Advanced machine vision, biosonar, acoustic, electromagnetic, magnetic, and tactile sensors will be coupled with primitive hunting and avoidance behaviors to give these vehicles extraordinary abilities to navigate autonomously and identify many of the man-made objects they encounter. New biomimetic based sensors will provide location, discrimination and classification of objects, such as mines buried in the mud or sand.

Power Projection

Power projection in the Navy After Next will incorporate new technologies in platform design and manufacture and in weapon lethality. New platform designs will make future ships and aircraft more effective, survivable and maintainable. Manufacturing improvements will make them more affordable. Weapon lethality will be improved across a broad spectrum

from distributed real time mission planning/replanning to cheaper, smaller, more accurate guidance and control and more energetic warheads.

- **Affordable reduced-manpower surface platforms will incorporate new materials, smart structures, optical fiber systems, conditioned based maintenance, autonomous systems and embedded training.** These technologies will reduce manning, production and life cycle costs. Additionally, advances in manufacturing technology, such as agile manufacturing and automated joining will enable the cost-effective production of ships with modular components so a basic design can be modified for different missions by adding or replacing modules for weapons, UAV's and sensor suites.
- **Stealthy, submersible or semisubmersible platforms will minimize missile vulnerability.** New platforms, made of a low signature material with a multi-faceted/fractal design, will provide high speed efficient transit. These platforms will be semisubmersible or submersible for self protection and have versatile flat areas for vertical launchers, UAVs and small craft operations. Its mission will include: fire support, preparing the coast for invasion, surveillance, and expeditionary warfare. It will also have the ability to deliver small submersibles (UUV's) for mine countermeasures, reconnaissance, and other mission support.
- **Future weapons will incorporate new materials, smart structures, autonomous controls, and status monitoring for increased shelf life.** Affordable manufacturing of materials incorporating embedded sensors, will enable future weapons to be "smarter", cheaper, and more stealthy. Distributed mission planning and in-flight control will allow these weapons to be employed more quickly and with the ability to support longer range autonomous weapons in a CAP-like role. Advances in smart submunitions will allow the tailoring of warhead packages to specific targets. Such submunitions will be able to discriminate among the various discrete frequencies associated with a complex mechanized

order of battle without the need for human spotters.

- **Gun technology will undergo revolutionary advancements.** Gun projectiles will use assisted flight from propulsors and ram jet or solid rocket, to extend ranges beyond 100 nautical miles. The addition of low cost Inertial Navigational System/Global Positioning System type guidance and aerodynamic controls will increase accuracy to that of a guided missile but at a fraction of the cost.
- **Strike missile technology with pinpoint accuracy will derive from advancements in aim point selection.** Precision aim-point targeting will virtually eliminate collateral damage. This pinpoint accuracy will increase the functional kill capability of missiles without having to increase warhead size.
- **Unmanned tactical air launch platforms will extend the strike distance controlled from ships.** Distributed command and control of delivery systems on CAP-like patrol will allow unmanned transport vehicles to loiter in tactically appropriate areas with a payload of strike missiles and bombs ready for launch on command from a control ship. This will effectively extend the range and reduce the time-to target of the strike missiles without having to increase the size or speed of missiles. This capability will also allow launching strike from forward areas without endangering crews.

Force Sustainment

Affordably sustaining the Navy after Next envisions innovative advances in non-petroleum energy sources, low-maintenance surface coatings coupled with entirely novel approaches to maintenance. Resulting decreased costs and increased readiness combine to make this a key focus for the Navy after Next.

- **Alternative energy non-petroleum based fuel sources will be key in future platforms.** Renewable high energy sources will yield fuel stocks for combustion/jet/rocket engines. They will reduce the need for strategic petroleum-based feed stocks and provide environmentally benign processes for production, process-

ing and use. Compact high density fuel cells, based on immobilized enzymatic redox capabilities, will yield long-lived low-power energy sources for sensor/detector packages, a wide variety of electro-optical devices for ROVs and other remote systems requiring low power for sustained periods of time (weeks to months). These fuel cells will be inexpensive, expendable, thermal/pressure stable and durable for deployment under adverse conditions for extended periods of time.

- **Integral signature management and fouling control in composite construction will produce low-maintenance, low signature platforms application.** Automated lay-up of composite structures with point-of-application mixing will allow build-up of signature control layers and application of final coatings to shed fouling or repel CBW agents. Block co-polymer coatings will yield self-cleaning, non-fouling, drag-reducing coatings for ship and submarine hulls, and for use on ROVs, moorings and unattended underwater systems. These coatings will be self-healing and will not be functionally impaired by abrasion or punctures and will provide a minimum of 10 years of operational service on steel, composite and polymeric materials. The coatings will reduce drag, thereby optimizing speed and performance of hulls, and contain acoustic energy propagation yielding acoustic signature control and enhancing stealth. Embedded and process specific sensors will be used to control lay-up process and to identify conditions requiring maintenance or repair.
- **Condition-based vice time-based maintenance will result in higher levels of readiness at significantly reduced cost.** Maintenance of complex mechanical machinery on Navy platforms will be performed on condition-based scheduling, reducing the costs of premature removal, keeping major assets ready, and reducing manpower requirements. This will be achieved by integrated maintenance/battle damage control systems. Sensor suites will be located at critical points on machinery, connected by fiber

optics and optic/electronic links. Advanced fault ID and failure prediction algorithms will use the data from these sensors and rapidly computable physical models to track the condition of the systems and direct condition-based maintenance. The enabling of CBM will also significantly reduce the logistics tail. The extensive sensor suites will also support automatic battle damage control. Some of these sensors will be combined with actuators in smart materials capable of limiting the spread of damage (eg. composite tearing). The 3-D displays indicating fault/damage location will also serve for embedded training of personnel on multiple damage scenarios, and will also permit a reduction in crew size with maintenance tasking.

Cross Cutting

Many of the required leap forward capabilities of the Navy After Next will impact all four critical operational domains. These cross-cutting capabilities will (1) enhance personnel readiness through revolutionary advances in training technologies; (2) improve strategic planning and decision-making through greatly enhanced and accurate environmental predictions; (3) simplify logistics support and life-cycle management through computer controlled manufacturing, maintenance and repair; (4) enhance stealth, signature control, and mission execution through the ability to exploit, smart control surfaces; and, (5) provide a comprehensive tactical picture through advances in data discrimination, integration and fusion optimize for the battlespace commander.

- **Embedded training systems will provide on-demand, anywhere/anytime advanced training capabilities.** Navy/Marine Corps personnel will receive timely training and on-line performance assessment to prevent skill perishability, significantly reducing instructors and shore training logistics. Advanced intelligent computer based-training systems will be capable of real-time on-line diagnosis of student conceptual or procedural errors and will prescribe and deliver individually optimized corrective instruction. Realistic simulations of naval systems

will provide the capability for joint and combined training in hybrid environments (live and virtual), full simulation, rehearsal capability for all expected missions both inter- and intra-ship. Training costs associated with changes in equipment will be minimal because virtual environment training systems will be reconfigurable and deployable.

- **Pharmaceutical advances will allow Navy/Marine Corps personnel to experience enhanced physical and cognitive performance as a result of improved sleep and reduced stress deficits.** Improved decision making will reduce human error and allow better use of advanced technologies. Disabling/distracting infections will be prevented by improved broad-spectrum mucosal vaccines. Injured personnel will be protected from life-threatening wound infections through immunoprotectants, extensive blood loss will be corrected by therapeutic oxygen-carrying resuscitation fluids that preserve vital organ function, and novel organ and limb transplantation strategies will permit recovery from more serious wounds without permanent disabilities.
- **Software and hardware advances will result in revolutionary information processing capabilities.** Intelligent machine-aided rapid production of reliable, reusable and secure software will reduce costs and prevent intentional or accidental interruption of information flow. Wireless computer networks will enable allied platforms to communicate by high rate data paths on a standard network. Real-time language translators and natural language computer interfaces will enable allies from different nations to communicate in real-time among combatant forces and with civilians in police actions.
- **Composite materials with embedded sensors and actuators will allow dynamic shape control for maneuver and performance optimization.** Strong, flexible materials of high-strength fiber and binders will be combined with electrostrictive actuators and fiber optic sensors to produce a platform shell that can reform

itself to adapt to its environment or operational need. Piloted or autonomous aircraft will be made seamlessly and will maneuver with adaptive surfaces.

- **Reliable 30-day forecasts of ocean and atmospheric conditions will optimize naval operations.** Enhanced computational capacity coupled with higher resolution space-based autonomous sensors systems will yield more comprehensive and accurate battlespace weather and sea condition nowcasting and forecasting through numerical models. The chaotic nature of air and marine conditions compromises long-term predictability requiring intelligent systems that will recognize patterns and exploit new paradigms in modeling and simulation to extend reliable prediction into the realm that will provide the battlespace commander

with significant advantages for sea-based, amphibious or air operations. Nowcasts will be visualized in three-dimensional displays with real-time model forecasting predictions available on command with regional specificity. Such capabilities should augment decision making in terms of type of weapon for the target, timing of assaults as well as providing a seamless interface with other concurrent battlespace activities.

- **Cybernetic agile manufacturing and repair will allow paperless manufacturing of platforms and weapons for minimum cost and independence from an under utilized industrial base.** Lean, right-the-first-time, paperless design, manufacturing and maintenance will reduce costs and lead-time for platform construction. Direct computer controlled lay-up of

composite structures with embedded sensors, data buses and printed wiring will eliminate naval dependence on a collapsing industrial based and permit automated repair of battle damage in remote locations. Virtual prototyping will obviate the need for physical prototyping. Complex products will be designed and distributed digitally among totally integrated organizations that include suppliers, producers and customers. Product properties and their behavior will be reliable simulated and manufacturing processes will be accurately modeled prior to build.

- **Advances in modeling and simulation will impact strategic planning, large scale physical models, e.g. meteorology, the acquisition process and affordable manufacturing.**



Figure 1: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.



Figure 2: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.



Figure 3: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.



Figure 4: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.



Figure 5: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.



Figure 6: 3D visualization of a complex, multi-faceted geometric structure, possibly representing a ship's hull or a complex object in a simulation.

Chiefs of Naval Research



VADM H. G. Bowen
July 1945 - October 1946



RADM P. F. Lee
November 1946 - June 1948



RADMT A. Solberg
July 1948 - June 1951



RADM C. M. Bolster
August 1951 - December 1953



RADM F. R. Furth
January 1954 - January 1956



RADM Rawson Bennett
January 1956 - January 1961



RADM L. D. Coates
January 1961 - June 1964



RADM J. K. Leydon
June 1964 - June 1967



RADMT B. Owens
July 1967 - June 1970



RADM C. O. Holmquist
June 1970 - June 1973



RADM M. D. Van Orden
June 1973 - July 1975



RADM R. K. Geiger
August 1975 - July 1978



RADM J. A. Baciocco
July 1978 - August 1981



RADM L. S. Kollmorgen
July 1981 - October 1983



RADM J. B. Mooney
November 1983 - August 1987



RADM J. R. Wilson
September 1987 - June 1990



RADM W. C. Miller
June 1990 - June 1993



RADM Marc Y. E. Pelaez
June 1993 - Present

Chief Scientists and Technical Directors



Dr. Alan T. Waterman
1946 - 1951



Dr. Emmanuel R. Plore
1951 - 1954



Dr. Thomas J. Killian
1955 - 1959



Dr. F. Joachim Weyl
1960 - 1965



Dr. Peter King
1965 - 1971



Dr. William P. Raney
1971 - 1978



Dr. Jerome A. Smith
1979 - 1983



Dr. Marvin Moss
1983 - 1987



Dr. Fred E. Saalfeld
1987 - Present

Dr. Bruce C. Heezen



Oceanographer Marie Tharp is shown in this photo from the early 1950's at her drawing board detailing one of her famous geophysical charts of the sea floor. She has been associated with Lamont-Doherty Geological Observatory, Columbia University, since its founding in 1949 until retiring in 1983. During this time she collaborated with the late Dr. Bruce C. Heezen in the study of sea floor topography; this work was funded by the Office of Naval Research for many years. In 1977 their studies resulted in the famous World Ocean Floor Panorama. This pictorial representation of the sea floor is based on more than 5,000,000 miles of soundings taken by oceanographic institutions and hydrographic bureaus of many countries and the bathymetric studies by Dr. Heezen and Marie Tharp. The chart remains today a standard for its accuracy in depicting the features of the ocean floor.